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The feasibility of a lagoon treatment-spray irrigation system for the combined domestic wastes and industrial wastewaters in Muskegon County, Michigan, was investigated in this study. The largest volume of industrial wastewaters are those discharged by a pulp and paper mill.

Various aspects of the project were investigated including: (1) sampling and analyses of wastewaters for a variety of parameters, (2) a review of available information concerning the effect of trace elements on soils and crops, (3) laboratory tests of the treatability of the combined wastewaters by lagoon treatment, (4) development of a simulation model to assist in analyzing the volume and water quality aspects of a treated wastewater storage lagoon, (5) soils and groundwater field and office studies regarding the management of groundwater levels to ensure an adequate aerobic treatment zone in the soil as well as to prevent ponding in the site area, and (6) investigations of certain agricultural aspects in using treated wastewaters as spray irrigation water.

The results of this work demonstrated the feasibility of the proposed project based on information developed during the study, the highlights of which are: (1) the wastewaters do not contain constituents having concentrations that would interfere with use of these wastewaters as agricultural irrigation waters, (2) the treatability of the wastes by the proposed lagoon treatment system was confirmed by the laboratory work, and (3) the feasibility of management of the groundwater levels within the irrigation site area by drainage wells and tile was established by the investigations. (See also W69-09331)

Abstractor

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ENGINEERING FEASIBILITY DEMONSTRATION STUDY
FOR MUSKEGON COUNTY, MICHIGAN
WASTEWATER TREATMENT-IRRIGATION SYSTEM

FEDERAL WATER QUALITY ADMINISTRATION
DEPARTMENT OF THE INTERIOR

By

Muskegon County Board
and Department of Public Works
County Building
Muskegon, Michigan 49440

Program #11010 FMY
September, 1970

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This report has been reviewed by the Federal Water Quality Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Quality Administration.

ABSTRACT

The feasibility of a lagoon treatment-spray irrigation system for the combined domestic wastes and industrial wastewaters in Muskegon County, Michigan, was investigated in this study. The largest volume of industrial wastewaters are those discharged by a pulp and paper mill.

Various aspects of the project were investigated including: (1) sampling and analyses of wastewaters for a variety of parameters, (2) a review of available information concerning the effect of trace elements on soils and crops, (3) laboratory tests of the treatability of the combined wastewaters by lagoon treatment, (4) development of a simulation model to assist in analyzing the volume and water quality aspects of a treated wastewater storage lagoon, (5) soils and groundwater field and office studies regarding the management of groundwater levels to ensure an adequate aerobic treatment zone in the soil as well as to prevent ponding in the site area, and (6) investigations of certain agricultural aspects in using treated wastewaters as spray irrigation water.

The results of this work demonstrated the feasibility of the proposed project based on information developed during the study, the highlights of which are: (1) the wastewaters do not contain constituents having concentrations that would interfere with use of these wastewaters as agricultural irrigation waters, (2) the treatability of the wastes by the proposed lagoon treatment system was confirmed by the laboratory work, and (3) the feasibility of management of the groundwater levels within the irrigation site area by drainage wells and tile was established by the investigations.

This report was submitted in fulfillment of Grant No. 11010 FMY between the Federal Water Quality Administration and the Muskegon County, Michigan, Board and Department of Public Works.

Key Words: Aerated lagoons, B.O.D. removal, groundwater management, soil treatment, wastewater irrigation, wastewater reuse, wastewater treatment.

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SECTION I

CONCLUSIONS

This study has confirmed the feasibility of a Muskegon County wastewater management system utilizing lagoon treatment and spray irrigation facilities. Additional results of these studies have been the development of information and tools which can be used in establishing the bases of design for the system.

Wastewater Analyses

The wastewater sample collection and analyses program resulted in a significant review of the heavy metals and other constituents in the influents and effluents of the City of Muskegon and City of Muskegon Heights sewage treatment plants. This work permits an assessment of the effects of primary treatment at Muskegon and activated sludge treatment at Muskegon Heights on the constituents tested.

The results indicate that the wastewaters examined are generally tupical of those containing domestic and industrial wastes. However, there were evidences that occasional dumping of strong industrial wastes into the wastewater collection system occurs. These findings support the need for sewer use regulations.

Trace Elements in Soils

An extensive review of the available information on the effect of trace elements in soils was made. Particular emphasis was placed on potential soil and crop toxicities resulting from the use of irrigation waters containing heavy metals.

A review of the available information on the significance of trace elements in soils and the wastewater sample test results reported in Section IV of this Report indicates that the present levels of trace elements in the Muskegon area wastewaters are not likely to interfere with its use as irrigation water. However, it is recognized that a trace element monitoring program should be included as a part of the operational framework of the wastewater management system. This program would be used to assure a wastewater of continuing acceptable quality.

Lagoon Treatment Laboratory Studies

The laboratory operations and tests performed confirmed the treatability of the combined Muskegon and S. D. Warren Co. wastewaters using aerated lagoons. Additional characteristics of the wastewaters and initial design information were also determined. Specific data and information developed were as follows:

1. Five-day Biochemical Oxygen Demand (BOD) average reductions of 70 to 90 percent occurred within the two and four-day detention periods.
2. Chlorine demands of the aerated lagoon effluent were such that a chlorine dosage of less than 10 mg./l. was sufficient for disinfection.
3. Algae growths will occur in the aerated lagoon effleunt.
4. Significant reductions of aerated lagoon effluent color, phosphates, and ammonia nitrogen occurred in the sand column filtration column tests. Phosphate levels were reduced to well below 0.1 mg./l., color to generally less than 5 units, and ammonia nitrogen reductions generally ranged from 50 to 75 percent.
5. The lagoon bottom sealing and other characteristics of the system sludge were investigated.

Simulation Model

Using the recorded Muskegon, Michigan climatological data for 1948 through 1969 as the basic input, the combined lagoon water quality and storage requirement mathematical model simulated the operation of the storage lagoons during this period for varying irrigation rates. Using a range of 1.5 to 2.5 inches per week of irrigation and generally not irrigating during times of freezing conditions or precipitation, the lagoon storage requirements generally varied between 3840 million gallons (32 MGD for 4 months) to 4800 million gallons (32 MGD for 5 months). These results were based on an irrigation area of about 9500 acres.

The water quality aspects of the simulation model at its present state of development indicates that the Biochemical Oxygen Demand and Dissolved Oxygen conditions in the storage lagoons would generally be at satisfactory levels. The period during "spring break-up" before aerobic conditions are restored is estimated at approximately 3 weeks.

The model is not viewed as a finished product, but rather as an initial tool which can be modified, refined, or expanded to assist in the final design of the system as well as establish operating procedures.

Soils and Groundwater Investigations

To permit the evaluation of the feasibility of groundwater control and management within the irrigation site area, nine soils test borings and two aquifer permeability tests were made. An extensive analysis of the data obtained from the field investigations permitted the assessment of two groundwater level management techniques, drainage wells and drainage tiles.

The results of this work established the feasibility of groundwater control within the irrigation site study area, with the particular management technique depending on the specific soils and aquifer conditions within the various subareas. Preliminary information indicates that drainage well spacing could range from 4,500 to 800 feet, and that drainage tile spacing could range from 1,500 to 200 feet.

Irrigation Agricultural Studies

This work included inputs from various agricultural disciplines and a review of the potential types of agricultural uses available for the land within the irrigation site area. Included were the following alternatives:

1. Sod production
2. Perennial grasses to be harvested as hay or pasture.
3. Continuation of Christmas tree production in selected areas
4. Beef cattle operations

The conclusions of the study were that the preferable agricultural use during the early stages of the project should be the production of perennial grasses with harvesting as hay or pasture. The results of the study also suggested that the implementation of other agricultural management alternatives, such as cultivated crop production or beef cattle operations, could follow.

SECTION II

RECOMMENDATIONS

As outlined in the Conclusions Section, this study has demonstrated the engineering feasibility of a wastewater lagoon treatment and irrigation system for Muskegon County, Michigan. Based on the results of this work, the following recommendations are made:

1. Proceed with the design and construction of the wastewater lagoon treatment and irrigation system for Muskegon County.
2. Develop a research and demonstration program for monitoring the operation of the system.
3. Expand the agricultural studies to include greater in-depth work including a review of commercial agricultural opportunities.

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SECTION III

INTRODUCTION

The initial reports, prepared by Bauer Engineering, Inc., concerning the development and feasibility of a Muskegon County wastewater management system utilizing spray irrigation of treated effluent were:

1. "Muskegon County Plan for Managing Waste Water," May 1969.
2. Appendix C - Design Basis for Muskegon County Plan for Managing Waste Water.

The proposed lagoon treatment - spray irrigation system included the following elements in the sequence listed:

1. A wastewater intercepting system including sewers, pumping stations, and force mains to convey the domestic sewage and industrial wastewaters to the aerated lagoons.
2. Aerated lagoons, utilizing mechanical surface aeration equipment, with 3-day detention capabilities.
3. Storage lagoons, having a volume equal to about 5 months of wastewater flow, for holding the treated wastewater during periods when irrigation can not be done.
4. Chlorination facilities to disinfect the storage lagoon effluent before using the treated wastewater for irrigation.
5. A spray irrigation system involving a pipeline distribution network and fix-pivoted, rotating, low pressure discharge irrigation rigs having lengths up to 2000 feet.
6. A drainage system, using wells and drain tile, within the 10,000 acre site area to control the level of groundwater to ensure an adequate aerobic soil treatment zone as

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well as to prevent the movement of groundwater out of the site area. The water collected by the drainage system would be discharged to the streams outside of the irrigated area.

After completion of the above mentioned reports, the decision was made to pursue additional studies and investigations regarding design and feasibility aspects of the proposed system. This additional work has been supported and financed, in part, by the Federal Water Quality Administration, Department of the Interior, pursuant to the Federal Water Pollution Control Act. This report presents the results of those additional studies.

The scope of the work, known as the "Phase A" studies, was originally outlined in Bauer Engineering, Inc.'s, "Research and Demonstration Proposal, Engineering Feasibility Demonstration Study for Muskegon County, Michigan, Wastewater Treatment - Irrigation System" November 26, 1969. This proposal established the work to be done within the framework of the following four components:

I - Wastewater System Inputs

II - Wastewater Transportation System

III - Wastewater Treatment System

IV - Agricultural Wastewater Irrigation System.

Component I

Under Component I, the collection and analyses of wastewater samples of the influent and effluent at the City of Muskegon and City of Muskegon Heights sewage treatment plants were to be accomplished. In addition, an interpretation of the data generated was to be made.

The collection and analyses program procedures were prepared by Gurnham and Associates, Inc. The wastewater sample collection was done by the Muskegon County Health Department under the direction of Tenco Hydro/Aerosciences, Inc. Tenco Hydro/Aerosciences, Inc. performed the wastewater sample analyses.

Sections IV and V of this report present the results of the work performed under Component I.

Component II

Included in this portion of the study was the evaluation of certain wastewater transmission main routing location alternatives. This work was of local interest only and therefore is not included in this report.

Component III

Component III covered the work of a literature review on lagoon treatment of wastewaters, laboratory pilot plant tests of the system influent, and a mathematical simulation model of the lagoon functioning.

Included in the laboratory work, which was performed by Tenco Hydro-Aerosciences, Inc., were:

1. Operation of bench-scale aerated lagoons, having different detention times and temperatures, treating a mixture of City of Muskegon wastewater and S. D. Warren Co. wastewater.
2. Determination of the system effluent chlorine demands.
3. Characteristics of the aerated lagoon effluent after storage.
4. Determination of the feasibility of algae production in the aerated lagoon effluent.
5. Lagoon sealing characteristics of the solids.
6. Although it was not outlined in the proposal, laboratory analyses of the system effluent were made before and after trickling through 5-foot and 10-foot columns of sand. The sand was obtained from the irrigation site area.

Although it was initially envisioned that the lagoon simulation model would be separate, it became apparent during the work that it should be incorporated with the irrigation simulation model of Component IV. The result of this merger was a mathematical model that simulated the lagoon storage requirements and water quality.

The results of the Component III work are reported in Sections VI and VII.

Component IV

The work to be accomplished under this heading was the development of an irrigation simulation model; the selection of the irrigation site area; an evaluation of the feasibility of groundwater control and management within the site area; and agricultural productivity, market, and cropping studies.

The irrigation site area soils and groundwater investigations were performed by the Layne-Northern Company, Inc. Included in their work were nine soils test hole borings and two aquifer test wells. The initial analysis of the test well data was performed by Dr. W. G. Keck, while the overall analysis and interpretation of the entire data was under the direction of Dr. James Hackett.

The evaluations of the agricultural aspects of the study were accomplished by various members of the Agricultural faculty at the Michigan State University, East Lansing, under the direction of the Department of Agricultural Economics.

Sections VII, VIII, and IX report the work done under Component IV.

References

A consequence of these studies was the assembly and review of a large number of references covering the topics under investigation. A listing of these references has been included in the report as Section XI and has been categorized under the headings: Wastewater Irrigation, Trace Elements in Soils, and Lagoon Treatment.

SECTION IV

WASTEWATER ANALYSES

Introduction

In order to determine the amounts of various heavy metals and other substances in the wastewaters within the Muskegon-Mona Lake area, a wastewater sampling and analyses program was conducted at the existing City of Muskegon and City of Muskegon Heights sewage treatment plants. Samples of the influent and effluent at each of the plants tested permitted observations of the effects on the constituents measured by activated sludge treatment at the Muskegon Heights plant and primary treatment at the Muskegon plant. Also included were analyses of selected parameters to determine the relative amounts of soluble and insoluble portions.

The results of the wastewater sample analyses are generally typical of those associated with wastewaters containing both domestic and industrial wastes. However, the data suggests that there are times when scattered dumping of strong industrial wastes into the wastewater collection system takes place. This indicates the need for sewer use regulations.

This study was made by Tenco Hydro/Aerosciences, Inc. who supervised the sample collection and performed the sample analyses in their laboratories in Chicago. The wastewater sample collection was performed by the Environmental Health Section of the Muskegon County Health Department.

General Procedures

Samples were collected for three weeks, seven days a week, at both the City of Muskegon Sewage Treatment Plant (Primary treatment) and at the Muskegon Heights Sewage Treatment Plant (Activated Sludge). The City of Muskegon treatment plant was sampled first from April 4th to April 24th. The Muskegon Heights treatment plant was sampled in two periods. The first period was from April 29th to May 12th, during which time lime was being used experimentally to reduce the phosphate in the effluent. The second period was from May 23rd to May 31st, at which time the plant operated under normal conditions (without lime addition).

Daily composites, weekly composites, and occasional grab samples were analyzed for trace metals, toxic compounds, nutrients and mineral composition. Hourly samples were checked for pH, prior to being composited. The scope was limited to measuring concentration patterns of the various parameters in both the influent and effluent of the two sewage treatment plants. Differences in concentration between filtered and unfiltered samples were also measured. No attempt was made to correlate plant operating data with variations in the influent composition.

The following parameters were measured daily:

- Cadmium
- Calcium
- Chromium
- Chloride
- Fluoride
- Copper
- Cyanide
- Iron
- Nickel
- Nitrogen (Ammonia)
- Hexane Solubles
- Phenol
- Sulfide
- Sulfate
- Zinc

The following parameters were measured weekly:

- Aluminum
- Arsenic
- Manganese
- Lead
- Nitrogen (Nitrate)
- Nitrogen (Organic)
- Phosphate (Total)
- Potassium
- Selenium
- Sodium
- Tin

Temperature was recorded daily and pH was checked hourly.

Collection of Samples

Samples were collected hourly from the influent channel and effluent channel at each of the sewage treatment plants by use of automatic samplers. Twenty-four individual samples were collected daily at each sampling point. Twelve bottles contained caustic to serve as a preservative for phenol and cyanide. The twelve other bottles did not contain any preservatives. The bottles were arranged so that every other hour a preserved sample was collected. The samples were brought to the Muskegon County Health Department, Environmental Health Section Laboratory daily for compositing and preparation for shipping. All samples were chilled and packed in an ice chest for shipment to Chicago the same day.

Sulphide samples were collected on an individual basis using a D.O. sampling can and plastic bottles. The samples were field stabilized.

Grab samples were collected either two or three times per week on different days and at various times. The grab samples were divided into two portions. One portion was split into two samples, one as received and one to which caustic was added as a preservative. An ammonia sample was also taken and preservative added. The other portion was filtered using coarse qualitative paper. The filtrate was then treated the same as the first portion.

The sampling was scheduled for seven days per week for three weeks at each plant. At the Muskegon Heights Sewage Treatment Plant it was necessary to split the sampling period into a fourteen day and a nine day period. This was due to experimental work on phosphate removal being conducted at the plant in April and early May. It was felt removal data under both experimental and standard conditions might prove useful.

Field Procedures

Every morning two staff members from the Environmental Health Section, Muskegon County Health Department would visit the sampling location, remove samplers and collect the 24 influent and 24 effluent samples. New bottles would be replaced in the automatic samplers, units activated, and replaced at sampling sites. Grab samples would be collected and sulphide samples field preserved using zinc acetate and sodium hydroxide. The automatic samplers used were SERCO samplers which contain 24 separate bottles attached to a single probe. All bottles were evacuated after being placed in a sampler. Each hour a closk released a trigger mechanism (a clamp on a hose) which allowed an evacuated bottle to siphon a sample through the probe into the bottle. Sulphide samples were collected in stainless steel D.O. sampling cans using a plastic bottle. After samples were brought to the laboratory (Muskegon County Health Department), the pH was measured on all samples without preservatives. Samples were then composited proportional to the average flow, both those with and without preservatives. The two composites were then poured into plastic bottles with polyseal caps and refrigerated prior to shipment. Additional samples were preserved with mercuric nitrate for ammonia determination.

On days when grab samples were collected, one half-gallon was shipped as collected and one half-gallon was shipped after caustic was added. A second gallon was filtered using filter paper and one half-gallon of filtrate was shipped as filtered and the other half-gallon was shipped after the sample was preserved with caustic. Filter paper was used instead of the preferred method of using a membrane filter because of sample volume requirements. The poor filterability of sewage gave a prohibitive filtering period with membrane filters. The pH was measured using a Beckman portable pH-meter, standardized daily.

Laboratory Procedures

Upon arrival at the laboratory in Chicago, samples were further processed. Samples for metals analyses were acidified. Aliquots of daily samples were composited for weekly analyses as listed in Scope of study.

All laboratory procedures used were either from "Standard Methods for the Examination of Water and Wastewater, 12th Edition, 1965, A.P.H.A." or "Federal Water Pollution Control Administration Laboratory Procedures, November 1969, Department of Interior". Table 1 lists all parameters and procedures used for this study. A Jarrel-Ash Maximum Versality Atomic Absorption Spectrophotometer was used for all atomic absorption measurements. A Bausch & Lomb Spectronic - 20 was used for colorimetric procedures.

Test Results

All data are summarized in Tables 2, 3, and 4, with the exception of pH and temperature. Most pH measurements at the Muskegon Sewage Treatment Plant varied between 7.0 and 8.0 units. The maximum value detected was 11.03 units and the minimum value was 2.62 pH units. Temperatures ranged from 10°C. to 14°C. at the Muskegon plant. At the Muskegon Heights Sewage Treatment Plant, the pH ranged from 6.8 to 8.4, with no extreme results. The temperature varied from 12°C. to 18°C.

TABLE 1: LABORATORY METHODOLOGY TABULATION

Parameter	Method	Reference
Aluminum	A.A.S.*	F.W.P.C.A.**
Arsenic	A.A.S.	F.W.P.C.A.
Cadmium	A.A.S.	F.W.P.C.A.
Calcium	A.A.S.	F.W.P.C.A.
Chloride	Titration	Std. Methods***
Chromium	A.A.S.	F.W.P.C.A.
Copper	A.A.S.	F.W.P.C.A.
Cyanide	Colorimetric	F.W.P.C.A.
Fluoride	Colorimetric (SPADNS)	Std. Methods
Hexane Solubles	Soxhlet Extraction	Std. Methods
Iron	A.A.S.	F.W.P.C.A.
Lead	A.A.S.	F.W.P.C.A.
Manganese	A.A.S.	F.W.P.C.A.
Nickel	A.A.S.	F.W.P.C.A.
Nitrogen (Ammonia)	Colorimetric-Technicon	F.W.P.C.A.
Nitrogen (Nitrate)	Colorimetric	Std. Methods
Nitrogen (Organic)	Colorimetric	Std. Methods
Phenol	Colorimetric	F.W.P.C.A.
Phosphate	Colorimetric	F.W.P.C.A.
Potassium	A.A.S.	F.W.P.C.A.
Selenium	A.A.S.	F.W.P.C.A.
Sodium	A.A.S.	F.W.P.C.A.
Sulfate	Turbidimetric	Std. Methods
Sulfide	Titration	Std. Methods
Tin	A.A.S.	F.W.P.C.A.
Zinc	A.A.S.	F.W.P.C.A.

*A.A.S. - Atomic Absorption Spectroscopy

**F.W.P.C.A. - Federal Water Pollution Control Administration, Laboratory Manual, November 1969.

***Std. Methods - Standard Methods for the Examination of Water and Wastewater, 12th Edition, 1965,A.P.H.A.

TABLE 2: SUMMARY OF ANALYSES-MUSKEGON SEWAGE TREATMENT PLANT

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Ammonia Nitrogen						
Max.	23.70	19.50	17.40	19.50	22.40	16.80
Avg.	16.89	14.80	13.22	17.21	14.27	12.81
Min.	9.00	11.25	10.00	14.60	8.75	8.50
Aluminum						
Max.	0.50	-	-	0.20	-	-
Avg.	0.41	-	-	0.07	-	-
Min.	0.31	-	-	<0.01	-	-
Arsenic						
Max.	<0.01	-	-	<0.01	-	-
Avg.	<0.01	-	-	<0.01	-	-
Min.	<0.01	-	-	<0.01	-	-
Cadmium						
Max.	0.076	0.045	0.019	0.076	0.025	0.013
Avg.	0.037	0.021	0.010	0.033	0.013	0.008
Min.	0.010	0.008	<0.001	0.008	0.008	<0.001
Calcium						
Max.	120.00	-	-	89.45	-	-
Avg.	89.35	-	-	85.05	-	-
Min.	50.30	-	-	76.25	-	-
Chloride						
Max.	89	-	-	97	-	-
Avg.	87	-	-	92	-	-
Min.	85	-	-	89	-	-
Chromium						
Max.	2.90	2.82	2.54	3.30	1.91	1.70
Avg.	1.64	1.43	1.18	1.45	1.18	1.01
Min.	0.15	0.01	0.01	0.10	0.57	0.53
Copper						
Max.	0.480	0.270	0.120	0.200	0.176	0.160
Avg.	0.126	0.111	0.057	0.093	0.091	0.059
Min.	0.060	0.050	0.015	0.030	0.025	0.030
Cyanide						
Max.	0.358	0.737	0.393	0.414	0.434	0.414
Avg.	0.170	0.322	0.216	0.184	0.181	0.162
Min.	0.008	0.017	0.012	0.005	0.027	0.025
Fluoride						
Max.	-	-	-	1.25	-	-
Avg.	-	-	-	1.00	-	-
Min.	-	-	-	0.50	-	-

TABLE 2
(continued)

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Hexane Solubles						
Max.	97	51	32	69	33	26
Avg.	55	42	24	36	28	18
Min.	27	17	12	15	19	8
Iron						
Max.	3.25	1.72	0.44	1.46	1.30	0.41
Avg.	1.51	1.11	0.36	0.99	0.69	0.32
Min.	0.62	0.47	0.25	0.52	0.46	0.21
Lead						
Max.	2.05	-	-	0.65	-	-
Avg.	1.35	-	-	0.51	-	-
Min.	0.88	-	-	0.33	-	-
Manganese						
Max.	0.18	-	-	0.24	-	-
Avg.	0.16	-	-	0.15	-	-
Min.	0.11	-	-	0.09	-	-
Nickel						
Max.	0.98	0.40	0.35	1.38	0.30	0.28
Avg.	0.34	0.29	0.24	0.38	0.21	0.20
Min.	0.04	0.13	0.10	0.04	0.13	0.13
Nitrate Nitrogen						
Max.	-	-	-	2.50	-	-
Avg.	-	-	-	0.89	-	-
Min.	-	-	-	0.05	-	-
Organic Nitrogen						
Max.	29.50	-	-	33.40	-	-
Avg.	22.87	-	-	23.02	-	-
Min.	13.25	-	-	10.65	-	-
Phosphate (P)						
Max.	3.94	-	-	3.75	-	-
Avg.	3.85	-	-	3.04	-	-
Min.	3.78	-	-	2.44	-	-
Phenol						
Max.	0.110	-	-	1.000	-	-
Avg.	0.063	-	-	0.593	-	-
Min.	0.041	-	-	0.290	-	-
Potassium						
Max.	11.23	-	-	11.23	-	-
Avg.	9.81	-	-	9.63	-	-
Min.	8.70	-	-	8.41	-	-

TABLE 2
(continued)

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Selenium						
Max.	0.200	-	-	0.200	-	-
Avg.	0.070	-	-	0.070	-	-
Min.	<0.005	-	-	<0.005	-	-
Sodium						
Max.	81.2	-	-	79.7	-	-
Avg.	65.3	-	-	65.6	-	-
Min.	44.8	-	-	42.0	-	-
Sulfate						
Max.	70.0	-	-	70.0	-	-
Avg.	52.5	-	-	66.1	-	-
Min.	42.5	-	-	62.0	-	-
Sulfide						
Max.	0	-	-	0	-	-
Avg.	0	-	-	0	-	-
Min.	0	-	-	0	-	-
Tin						
Max.	<0.10	-	-	<0.10	-	-
Avg.	<0.10	-	-	<0.10	-	-
Min.	<0.10	-	-	<0.10	-	-
Zinc						
Max.	9.95	1.78	0.85	2.86	2.00	1.25
Avg.	1.80	0.74	0.31	1.18	0.70	0.43
Min.	0.22	0.28	0.11	0.19	0.14	0.10

TABLE 3: SUMMARY OF ANALYSES-MUSKEGON HEIGHTS SEWAGE TREATMENT PLANT (PERIOD WITH LIME TREATMENT)

Parameter	Influent-mg./l. Composite	Influent-mg./l. Grab Total	Influent-mg./l. Grab Filtered	Effluent-mg./l. Composite	Effluent-mg./l. Grab Total	Effluent-mg./l. Grab Filtered
Ammonia Nitrogen						
Max.	31.15	46.35	34.25	31.15	32.15	28.60
Avg.	27.08	46.35	34.25	27.35	32.15	28.60
Min.	22.00	46.35	34.25	24.00	32.15	28.60
Aluminum						
Max.	0.44	-	-	<0.01	-	-
Avg.	0.35	-	-	<0.01	-	-
Min.	0.26	-	-	<0.01	-	-
Arsenic						
Max.	<0.01	-	-	<0.01	-	-
Avg.	<0.01	-	-	<0.01	-	-
Min.	<0.01	-	-	<0.01	-	-
Cadmium						
Max.	0.115	0.037	<0.001	0.012	<0.001	<0.001
Avg.	0.038	0.037	<0.001	0.004	<0.001	<0.001
Min.	<0.001	0.037	<0.001	<0.001	<0.001	<0.001
Calcium						
Max.	108.6	-	-	143.5	-	-
Avg.	102.8	-	-	129.6	-	-
Min.	97.1	-	-	115.7	-	-
Chloride						
Max.	127	-	-	127	-	-
Avg.	126	-	-	122	-	-
Min.	125	-	-	117	-	-
Chromium						
Max.	1.66	0.39	0.14	0.20	0.14	0.02
Avg.	0.53	0.39	0.14	0.07	0.14	0.02
Min.	<0.01	0.39	0.14	<0.01	0.14	0.02
Copper						
Max.	0.213	0.297	0.165	0.140	0.030	0.030
Avg.	0.131	0.297	0.165	0.082	0.030	0.030
Min.	0.014	0.297	0.165	0.006	0.030	0.030
Cyanide						
Max.	.250	.53]	.461	.203	.017	0
Avg.	.135	.532	.461	.091	.017	0
Min.	.040	.532	.461	.016	.017	0
Fluoride						
Max.	-	-	-	0.75	-	-
Avg.	-	-	-	0.75	-	-
Min.	-	-	-	0.75	-	-

TABLE 3
(continued)

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Hexane Solubles						
Max.	99	107	29	149	11	10
Avg.	63	107	29	27	11	10
Min.	15	107	29	2	11	10
Iron						
Max.	3.40	1.49	0.40	4.00	0.04	0.02
Avg.	1.41	1.49	0.40	0.73	0.04	0.02
Min.	0.31	1.49	0.40	0.11	0.04	0.02
Lead						
Max.	4.50	-	-	0.50	-	-
Avg.	2.63	-	-	0.35	-	-
Min.	0.76	-	-	0.20	-	-
Manganese						
Max.	0.21	-	-	0.04	-	-
Avg.	0.18	-	-	0.04	-	-
Min.	0.16	-	-	0.04	-	-
Nickel						
Max.	0.16	0.07	0.03	0.11	<0.01	<0.01
Avg.	0.06	0.07	0.03	0.06	<0.01	<0.01
Min.	<0.01	0.07	0.03	<0.01	<0.01	<0.01
Nitrate Nitrogen						
Max.	-	-	-	0.14	-	-
Avg.	-	-	-	0.12	-	-
Min.	-	-	-	0.09	-	-
Organic Nitrogen						
Max.	25.10	-	-	15.00	-	-
Avg.	18.58	-	-	14.60	-	-
Min.	12.05	-	-	14.20	-	-
Phosphate (P)						
Max.	12.65	-	-	3.84	-	-
Avg.	12.42	-	-	3.32	-	-
Min.	12.20	-	-	2.81	-	-
Phenol						
Max.	1.720	-	-	0.048	-	-
Avg.	0.574	-	-	0.024	-	-
Min.	0.260	-	-	0.011	-	-
Potassium						
Max.	16.0	-	-	16.0	-	-
Avg.	15.5	-	-	12.0	-	-
Min.	15.0	-	-	8.0	-	-

TABLE 3
(continued)

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Selenium						
Max.	0.005	-	-	0.005	-	-
Avg.	0.002	-	-	0.002	-	-
Min.	<0.005	-	-	<0.005	-	-
Sodium						
Max.	93.0	-	-	85.0	-	-
Avg.	86.5	-	-	80.0	-	-
Min.	80.0	-	-	75.0	-	-
Sulfate						
Max.	80.0	-	-	97.5	-	-
Avg.	80.0	-	-	88.8	-	-
Min.	80.0	-	-	80.0	-	-
Sulfide						
Max.	2.40	-	-	0.51	-	-
Avg.	0.28	-	-	0.06	-	-
Min.	0	-	-	0	-	-
Tin						
Max.	<0.1	-	-	<0.1	-	-
Avg.	<0.1	-	-	<0.1	-	-
Min.	<0.1	-	-	<0.1	-	-
Zinc						
Max.	0.47	0.07	0.03	0.20	0.10	0.06
Avg.	0.30	0.07	0.03	0.11	0.10	0.06
Min.	0.20	0.07	0.03	0.04	0.10	0.06

TABLE 4: SUMMARY OF ANALYSES-MUSKEGON HEIGHTS SEWAGE TREATMENT PLANT (PERIOD WITHOUT LIME TREATMENT)

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Ammonia Nitrogen						
Max.	28.50	-	-	30.00	-	-
Avg.	23.56	-	-	25.29	-	-
Min.	18.75	-	-	19.50	-	-
Aluminum						
Max.	0.22	-	-	<0.01	-	-
Avg.	0.22	-	-	<0.01	-	-
Min.	0.22	-	-	<0.01	-	-
Arsenic						
Max.	0.09	-	-	0.29	-	-
Avg.	0.09	-	-	0.29	-	-
Min.	0.09	-	-	0.29	-	-
Cadmium						
Max.	0.045	0.021	0.021	0.037	0.013	0.008
Avg.	0.022	0.021	0.017	0.015	0.009	0.004
Min.	0.002	0.020	0.009	0.003	0.003	0.001
Calcium						
Max.	50.0	-	-	98.1	-	-
Avg.	50.0	-	-	98.1	-	-
Min.	50.0	-	-	98.1	-	-
Chloride						
Max.	109	-	-	110	-	-
Avg.	109	-	-	110	-	-
Min.	109	-	-	110	-	-
Chromium						
Max.	0.64	0.24	0.06	0.14	0.09	0.04
Avg.	0.26	0.17	0.04	0.10	0.09	0.04
Min.	0.10	0.12	0.02	0.05	0.09	0.03
Copper						
Max.	0.150	0.130	0.060	0.148	0.060	0.020
Avg.	0.087	0.80	0.040	0.062	0.038	0.011
Min.	0.050	0.050	0.030	0.030	0.025	0.005
Cyanide						
Max.	.181	.213	.213	.120	.060	.052
Avg.	.072	.089	.086	.059	.037	.022
Min.	.002	.004	.004	.024	.013	.002
Fluoride						
Max.	-	-	-	0.30	-	-
Avg.	-	-	-	0.30	-	-
Min.	-	-	-	0.30	-	-

TABLE 4
(continued)

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Hexane Solubles						
Max.	96	63	36	23	18	17
Avg.	71	49	27	13	13	10
Min.	41	40	17	7	8	5
Iron						
Max.	1.42	1.01	0.43	3.88	0.44	0.22
Avg.	0.92	0.87	0.39	0.70	0.34	0.13
Min.	0.28	0.73	0.35	0.20	0.23	0.07
Lead						
Max.	1.01	-	-	0.30	-	-
Avg.	1.01	-	-	0.30	-	-
Min.	1.01	-	-	0.30	-	-
Manganese						
Max.	0.99	-	-	0.15	-	-
Avg.	0.99	-	-	0.15	-	-
Min.	0.99	-	-	0.15	-	-
Nickel						
Max.	0.19	0.06	0.06	0.13	0.05	0.04
Avg.	0.07	0.04	0.04	0.07	0.04	0.03
Min.	0.01	<0.01	<0.01	0.01	0.03	0.02
Nitrate Nitrogen						
Max.	-	-	-	0.06	-	-
Avg.	-	-	-	0.06	-	-
Min.	-	-	-	0.06	-	-
Organic Nitrogen						
Max.	24.90	-	-	15.40	-	-
Avg.	24.90	-	-	15.40	-	-
Min.	24.90	-	-	15.40	-	-
Phosphate (P)						
Max.	12.20	-	-	12.65	-	-
Avg.	12.20	-	-	12.65	-	-
Min.	12.20	-	-	12.65	-	-
Phenol						
Max.	0.420	-	-	0.071	-	-
Avg.	0.231	-	-	0.021	-	-
Min.	0.120	-	-	0.006	-	-
Potassium						
Max.	11.0	-	-	18.0	-	-
Avg.	11.0	-	-	18.0	-	-
Min.	11.0	-	-	18.0	-	-

TABLE 4
(continued)

	Influent-mg./l.			Effluent-mg./l.		
		Grab			Grab	
Parameter	Composite	Total	Filtered	Composite	Total	Filtered
Selenium						
Max.	0.090	-	-	0.290	-	-
Avg.	0.090	-	-	0.290	-	-
Min.	0.090	-	-	0.290	-	-
Sodium						
Max.	83.8	-	-	90.0	-	-
Avg.	83.8	-	-	90.0	-	-
Min.	83.8	-	-	90.0	-	-
Sulfate						
Max.	66.2	-	-	92.5	-	-
Avg.	66.2	-	-	92.5	-	-
Min.	66.2	-	-	92.5	-	-
Sulfide						
Max.	0.17	-	-	0	-	-
Avg.	0.03	-	-	0	-	-
Min.	0	-	-	0	-	-
Tin						
Max.	<0.1	-	-	<0.1	-	-
Avg.	<0.1	-	-	<0.1	-	-
Min.	<0.1	-	-	<0.1	-	-
Zinc						
Max.	0.34	0.27	0.17	0.29	0.12	0.17
Avg.	0.25	0.24	0.14	0.14	0.10	0.07
Min.	0.12	0.18	0.12	0.09	0.07	0.07

The concentrations of parameters reported in Tables 2, 3, and 4 are reasonable for an industrial waste-sewage system such as Muskegon and Muskegon Heights except for phenol. The phenol concentrations found in the Muskegon Sewage Treatment Plant influent and effluent appear to be reversed, with the effluent being about 10 times higher than the influent.

The samples could not have been reversed for 21 days for phenol analysis since the hexane solubles analysis is taken from the same bottle as the phenol and appears correct. With an automatic SERCO sampler, a sample is collected for only about 5 seconds per hour. It is suggested that the phenol pollutant is a slug flow of short duration and high concentration. This change in distribution would increase the probability of collecting a sample containing phenol. It should also be noted that a small pumping station, serving the hospital, pumps intermittently at a rather high rate. It is possible that phenolic wastes from this area may surge through and not be sampled in the influent. The pumping station was usually activated between 9 and 10 a.m., during which period the bottles in the samplers were being changed.

The occasional higher values found in both the influent and/or effluent indicate the possibility of dumps of strong waste which could upset a short detention period biological system. In particular, the very high and very low pH values detected could easily upset a system and suggest that other toxic materials may also have been discharged but not detected. All attempts to isolate dumps of heavy metals, cyanide, or other toxic materials have been unsuccessful and limited by the time and funds available in the present study.

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SECTION V

TRACE ELEMENTS IN SOILS

Introduction

Trace elements are those which normally occur in water or soil in very small quantities. Some may be essential for plant growth in very small amounts while others are non-essential. In FWPCA's *Report of the Committee on Water Quality Criteria* (203) a list of trace elements is given as follows: aluminum, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, iron, fluorine, lead, lithium, manganese, molybdenum, nickel, selenium, tin, tungsten, titanium, vandium and zinc.

Trace element contents in sewage vary greatly among municipalities. The elements typically contained in sewage derived from municipal and industrial sources are: chromium, manganese, iron, cobalt, nickel, copper, zinc, molybdenum, cadmium and lead. The contents also vary on a daily or seasonal basis and may range from below detectable limits in some samples to concentrations in excess of 1000 mg/l for common elements such as iron.

The reason for the investigation of the effects of trace elements in soils is to determine what, if any, long-term, toxic soils conditions may evolve through the continued use of treated wastewater for irrigation. The toxicities are generally related to heavy metal concentrations in excess of that which can be tolerated by the soil or plants. The approach to this study has been to review extensively the avavailable information on this topic.

The value of treated sewage and digested sludge as soil conditioner to stimulate plant growth has been widely recognized. With an increase in public acceptance, the application of sludge to soils for ultimate sludge disposal and soil improvement will become increasingly common. Sludges are not balanced fertilizers. They are high neither in nitrogen nor in phosphorus and are low to very low in potassium. Evans (178) reports that heavy sludge applications containing copper, boron and zinc have also produced toxic effects on vegetables, particularly spinach and beans, when grown in acid soils.

The majority of research thus far conducted on treated sewage and wasted sludge as possible fertilizing materials in the United States has dealt with only applications covering a

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short span of time. Research dealing with trace elements in soils has been aimed at the beneficial use of the trace elements as plant nutrients. No clear evidence of toxicities and yield reductions to crops have been reported in the literature, perhaps because of the relatively short experience of farm utilization and relatively low rates of application.

Long-term application of sewage to farms has been experienced in Europe. Rohde (207) indicates that continuous applications of sewage sludge containing significant amounts of trace elements to agricultural soils could eventually reduce crop yields to uneconomical levels due to developed toxicity. Rohde's work appears to be the only well-documented report of heavy metal toxicity to plants induced by long-term application of sewage to agricultural land (87 years at Paris). Not enough research has been done regarding long-term disposition of trace elements and the effects on crops. However, Horn (185) suggests that estimates of relatively short-term (less than about 50 years) effects of sludge on soil properties can be based on existing knowledge of soil compositions and the chemical, bio-chemical, and physical systems operative in natural soils.

Trace Elements in Sewage and Sludge

Horn (185) presents general concentrations of trace elements that can be expected in sewage sludge from large municipalities in Table 5. These elements are also present in most mineral soils but in much different proportions than those existing in sewage.

Trace elements in both raw sewage and treated sewage were determined from composite samples collected at the Muskegon Sewage Treatment Plant and the Muskegon Heights Sewage Treatment Plant. The ranges of concentrations are presented in Table 6. More detailed information is included in Section IV of this Report.

Trace Elements in Soils

Typical ranges of trace elements in soils are shown in Table 7. Iron, a very common constituent of soils, and cadmium, an exceedingly minor constituent, have been omitted from this table.

The character of soils affects the amounts of heavy metals retained on a long-term basis. Soils with high clay

TABLE 5: TRACE ELEMENTS IN SEWAGE SLUDGE

	Concentration-mg./l.			
	MSDGC		San Diego	
Elements	Range	Average	Range	Average
Chromium (Cr)	26-580	181	0	0
Manganese (Mn)	5-143	48	ND**	--
Iron (Fe)	661-9740	2297	ND	--
Cobalt (Co)	BDL*	--	ND	--
Nickel (Ni)	Trace-150	30	0-0.75	0.1
Copper (Co)	24-690	143	20-33	28
Zinc (Zn)	90-2280	--	67-200	127
Molybdenum (Mo)	BDL-0.06	--	ND	--
Cadmium (Cd)	1-110	22	0.2.5	0.4
Lead (Pb)	6-510	98	3-11	6

Sources of Data: The Metropolitan Sanitary District of Greater Chicago (MSDGC) and the City of San Diego, Calif.

*Below detectable limits.
**Not determined.

TABLE 6: TRACE ELEMENTS IN MUSKEGON SEWAGE

Element	Muskegon Primary Sewage* Treatment Plant-mg./l.		Muskegon Heights Secondary* Treatment Plant-mg./l.	
	Influent	Effluent	Influent	Effluent
Cadmium	0.010 - 0.076	0.008 - 0.076	<0.001 - 0.115	<0.001 - 0.037
Chromium	0.15 - 2.90	0.10 - 3.30	<0.01 - 1.66	<0.01 - 0.20
Copper	0.060 - 0.480	0.030 - 0.200	0.014 - 0.213	0.006 - 0.148
Iron	0.62 - 3.25	0.52 - 1.46	0.28 - 3.40	0.11 - 4.00
Nickel	0.04 - 0.98	0.04 - 1.38	<0.01 - 0.19	<0.01 - 0.13
Zinc	0.22 - 9.95	0.19 - 2.86	0.12 - 0.47	0.04 - 0.29

*Data includes test results of composite samples from April 4 to April 24, 1970 for Muskegon Sewage Treatment Plant and April 29 to May 31, 1970 for Muskegon Heights Sewage Treatment Plant.

TABLE 7: TRACE ELEMENTS IN SOILS

Elements	Typical Range, ppm	Possible Range, ppm
Manganese (Mn)	200-1,450	3-10,000+
Chromium (Cr)	5-1,000	0.5-10,000+
Nickel (Ni)	5-500	0.4-4,500
Zinc (Zn)	10-300	2-4,500
Lead (Pb)	2-200	0.2-2,500
Copper (co)	2-100	0.1-250
Cobalt (Co)	1-35	0.1-100
Molybdenum (Mo)	0.2-5	0.1-200

Source: Mitchell, R. L., "Trace Elements in Chemistry of the Soil," Ed. F. E. Bear, Reinhold Publishing Corp., N.Y. (1955).

contents have a greater capacity to absorb heavy metals owing to fixation. Mineral soils containing large percentages of layer silicate clay materials can fix substantial amounts of heavy metals within their crystal lattices and also hold them rather tightly as exchangeable cations on their negatively charged surfaces. The exchangeable cations are available to plants but are not easily replaced by other common soil cations. Copper and other metals held by clays, will have strong residual effects which are harder to eliminate once established in the soil.

On the other hand, sandy soils with little or no content of clay minerals display little tendency for fixation of metals by this mechanism. Sandy soils have a high proportion of quartz which has no ability to absorb heavy metals. Fixation that will occur in sandy soils is mainly a function of the amount of organic matter present.

In either soil type, an increase in organic content or an increase in soil pH to a near neutral or alkaline state will increase its ability to retain heavy metals.

Generally, heavy metals, with the exception of molybdenum are more soluble in the acid range and become highly mobile when the soil is below a pH of five. Heavy applications of acid-forming nitrogen fertilizers may lower the pH and lead to heavy metal toxicity. Such cases of toxicity may be overcome by lime application. The addition of lime results in the formation of insoluble carbonates of the heavy metals and also fixation as phosphates.

It is well known that the heavy metals in soils are closely associated with organic compounds forming stable organo-metal complexes. Regardless of the nature of the complexing agent, the stability of organic complexes of bi-valent metal ions involves the following order Cu, Ni, Co, Zn. Cd, Fe, Mn (Irving-Williams series) (190).

In general, heavy metal elements complexed by organic compounds are fixed and largely unavailable to plants. Soil organic matter therefore plays a vital role in the fixation of applied heavy metals. In soils, the highest contents of heavy metals occur near the surface where organic matter content is also normally greatest. This has led to the suggestion that where toxic quantities of heavy materials exist in the topsoil, deep plowing might gradually alleviate the condition both by dilution and by subsequent release of the metal through gradual acidification and loss of organic matter in the lower depths (210).

Heavy metals in soils with a high pH and containing carbonates are precipitated in an insoluble form as carbonates and also as phosphates. This recation is the basis for liming to correct heavy metal toxicities associated with acid soils. Frequently, in soils incompletely leached of carbonates, the metals are concentrated in subsoil horizons where carbonates are present and the pH is high. Uniform distribution of these elements in soil profiles cannot therefore be assumed (181).

Heavy metals that are not taken up by plants or fixed by stable organic compounds and clay minerals can be leached to the groundwater. Certain organic compounds are water soluble and having chelating properties. These can complex metals, prevent their precipitation and allow them to be leached. Mineral acids associated with mine drainage can also be highly effective in dissolving and carrying metal salts into groundwater and surface waters. Conditions that favor leaching also favor increased availability to plants and, therefore, many cases of metal toxicities have been associated with soils and waters of a very low pH. Despite this, heavy metals are for the most part fixed in soils and not leached out as indicated by the low heavy metal contents in lakes and streams. Due to the higher pH of sludge and the low buffering capacity of sands, the pH should be increased to near neutrality in a short period of time.

Effects of Trace Elements on Plants

Horn (185) has pointed out that the application of sludge to soils not only improves soil structure but also contributes major plant nutrients and micronutrients. He has discussed extensively both the heavy metal effects on soil and the nutritional aspects of a sludge - soil mixture. However he has also pointed out that while certain soil properties benefit from light or short-term applications of sludge, continued heavy applications may eventually become detrimental.

Lunin et al (203) states: When an element is added to the soil in toxic amounts, it may combine with it to give either of two results. First, it may decrease in concentration so that it is no longer toxic. Second, it may increase the concentration of that element in the soil. If the process of adding irrigation water containing a toxic level of the element continues, a steady state will be approached with time in which the amount of the element leaving the soil in the drainage water will equal the amount added with the irrigation water, no further change in concentration in the soil will occur.

Therefore, irrigation water containing trace elements may be added for many years before a steady state is approached. A situation can exist then where soil toxicities may not develop for years, decades or even centuries from the continued addition of irrigation waters. The time would depend on factors apart from properties of the water itself. Changes in technology and economy could easily alter circumstances significantly in such a long time.

Genetic differences in tolerance of plants to different elements or ions has been mentioned. Variability among species is well recognized. Recent investigations by Foy et al (182), working with soluble aluminum in soils, has demonstrated that there is also variability among varieties within a given species. This suggests the possibility of breeding varieties to minimize phytotoxicity which may result from a constituent in irrigation water.

Research dealing with effects of trace elements on plant growth does not permit, in general, any conclusions regarding threshold values beyond which a specific plant will react favorably. Most studies have been carried out with several plant species in sand or solution cultures under a wide variety of environmental conditions. It is difficult to extrapolate from these sand and solution cultures to soil conditions.

Soil conditions could influence the availability of the element to the plant. Thus, amounts of elements that can be tolerated in certain types of soil would not be tolerated in other soils. Comprehensive reviews of literature dealing with trace element effects on plants have recently been published (167) (170) (202). Additional research is needed to predict reactions between ions in irrigation water and various soil types, and the resultant effect on various plant species.

Limits for Irrigation Water

Lunin et al (203), developing a workable program of acceptable limits for trace elements in irrigation waters, defines two types of soil groupings that may be irrigated: (a) lands having a significant fraction of well-drained soils classified as sands, loamy sands, or sandy loams, and (b) lands, made up principally of finer textured soils and generally more slowly drained.

Individual minor element limits for water to be used on type "a" lands are calculated assuming that steady state may be approached in a relatively short period of time and, therefore, that the concentration in irrigation waters approximates that of soil solution. Upper limits that may be set for minor element tolerances in water for type "b" lands are somewhat more arbitrary. They are drawn largely from maximum safe fertilizer additions that might be applied to soils under the most favorable conditions for fixing the element in the soil. Table 8 shows the suggested trace element tolerances for irrigation waters.

Sodium Adsorption Ratio

Salinity and the ratio of sodium to calcium and magnesium are important factors in judging the suitability of water for irrigation. Soils commonly are not adversely affected by saline irrigation waters if the sodium concentration is low in relation to the concentration of calcium and magnesium, but plants have difficulty in extracting water from saline soil solutions. The osmotic pressure of such solutions interferes with the movement of water from the solution into the plant root, and under these conditions, the plants may suffer from incipient drought.

A sodium adsorption ratio (SAR), which is a measure of the effect of irrigation water on soil, of 8 or less is considered safe for all uses in agricultural crop irrigation. Values of 12 to 20 are marginal and continued use of waters with values much greater than 20 would lead to decreases in permeability. Soils with high SAR's are relatively impermeable to air and water. They are hard when dry, difficult to till, and plastic and sticky when wet. These adverse physical conditions retard or prevent germitation and water removal by plants and are generally unfavorable for plant growth.

The anticipated sodium adsorption ratio for the Muskegon wastewaters appears less than 3, an indication of a balanced concentration of sodium as against calcium and magnesium. Table 9 presents the SAR values of the raw wastewater and the treated effluents at various stages of treatment in the proposed lagoon system as indicated by the results of laboratory pilot studies.

Conclusions

A review of the available information on the significance of trace elements in soils and the wastewater sample test results reported in Section IV of this Report indicates that the present levels of trace elements in the Muskegon area wastewaters are not likely to interfere with

TABLE 8: TRACE ELEMENT TOLERANCES FOR IRRIGATION WATERS

Element	For Water Used Continuously on All Soils (mg/l)	For Short-Term Use** On Fine Textured Soils Only (mg/l)
Aluminum	1.0	20.0
Arsenic	1.0	10.0
Beryllium	0.5	1.0
Boron	0.75	2.0
Cadmium	0.005	0.05
Chromium	5.0	20.0
Cobalt	0.2	10.0
Copper	0.2	5.0
Fluorine	*	*
Iron	*	*
Lead	5.0	20.0
Lithium	5.0	5.0
Manganese	2.0	20.0
Molybdenum	0.005	0.05
Nickel	0.5	2.0
Selenium	0.05	0.05
Tin	*	*
Tungsten	*	*
Vanadium	10.0	10.0
Zinc	5.0	10.0

*No limits proposed.

**The term "short-term" used here means a period of time as long as 20 years.

Source: FWPCA, "Water Quality Criteria," (1968). Reference 203.

TABLE 9: SODIUM ADSORPTION RATIO OF MUSKEGON WASTEWATER

		Mixed Liquor 2-Day Detention		Filtered	
Item	Feed	@21°C	@4°C	@21°C	@4°C
Sodium, mg/l	125.0	119.6	118.0	105.5	105.5
me/l	5.44	5.20	5.13	4.57	4.57
Calcium, mg/l	330.4	110.6	200.0	121.9	118.1
me/l	16.5	5.52	10.0	6.08	5.89
Magnesium, mg/l	12.0	12.5	12.0	13.0	12.0
me/l	0.99	1.03	0.99	1.07	0.99
SAR	1.84	2.87	2.19	2.42	2.47

Note: 1. SAR = Na/ $\sqrt{(Ca + Mg)/2}$ (in me/l.)

2. Feed composed of 2 parts of domestic sewage and 3 parts of paper mill wastes from S. D. Warren Company.

with its use as irrigation water. However, it is recognized that a trace element monitoring program should be included as a part of the operational framework of the wastewater management system. This program would be used to assure a wastewater of continuing acceptable quality.

SECTION VI

LAGOON TREATMENT LABORATORY STUDIES

Introduction

Included in the laboratory studies were bench-scale operations and tests to demonstrate the feasibility and effects of different unit processes as well as to determine initial design parameter values. This work, performed in the laboratories of Tenco Hydro/Aerosciences, comprised the following investigations:

1. Bench scale operations of aerated lagoons with varying detention times and temperatures treating a combination of the City of Muskegon and S. D. Warren Company wastewaters. This work demonstrated the treatability of the waste with average biochemical oxygen demand (BOD) reductions ranging from 70 to 90 percent with two to four days detention. Also developed were aeration and oxygen demand factors which will be useful in preparing the basis of design for the aeration equipment.

2. Chlorine demand tests on the aerated lagoon effluent. These tests demonstrated that reasonable chlorine dosages (up to 10 mg./l.) would be required for disinfection.

3. Sand sealing characteristics of the system solids. This was performed to simulate the degree to which these solids would assist in sealing the bottom of the storage lagoon.

4. Sludge gas production of the system solids. This test assisted in the determination of certain characteristics of system sludge.

5. Algae growth tests on the aerated lagoon effluent. The results confirmed that algae growths would occur in the storage lagoons.

6. Column filtration tests of the aerated lagoon effluent. These tests were run to determine the effect of sand filtration on the color, phosphates, and nitrogen present in the

aerated lagoon effluent. The tests, performed with 5-foot and 10-foot columns containing sandy soils from the irrigation site area, showed significant reductions in color, phosphates, and ammonia nitrogen.

Scope of Work

The purpose of this investigation was to conduct laboratory studies on various aspects of the plan for treating municipal raw sewage with pulp and paper wastewater. This plan includes the treatment of the sewage - paper waste mixture by aerated lagoons, followed by storage lagoon impoundment of the aerated lagoon effluent. Water from the storage lagoon will be used for irrigation. Basic evaluation parameters were BOD and filterable solids reduction plus effluent BOD and filterable solids (suspended solids) content as a function of detention. Other design parameters included oxygen uptake rate, alpha factor, oxygen transfer efficiency and k_1 BOD reaction rate values. Raw sewage collected at the City of Muskegon Sewage Treatment Plant and wastewater from the S. D. Warren Company (Division of Scott Paper Company) were used for this study.

Treatment by aerated lagoons was simulated in the laboratory using the fill-and-draw method and detention times of 2, 4 and 6 days in constant temperature baths. Summer and winter performances were approximated by operating the pilot units at 20°C and 5°C.

The permeability of Muskegon soils using laboratory lagoon effluent was tested, and the sealing ability of the suspended solids was determinated.

The rate of gas production was measured from settled sludge which will accumulate in the deep pond. This condition was simulated in the laboratory by first collecting and refrigerating settled waste solids from the aeration units. Then the sludge was allowed to ferment at approximately 22°C.

The quality of underground seepage from lagoon supernatant (irrigation water) was also investigated using sand columns of 5 and 10 feet. Also studied was the chlorine demand of the lagoon supernatant as well as the growth of algae therein.

Laboratory Procedures

Aerated Lagoons

The duration for the aerated lagoon study was 5 weeks. Reaction cell volumes were 7, 7, and 10 liters for 2, 4 and 6-day units, respectively; one set of three for each temperature of 20° and 5°C. Water baths were used to maintain the desired temperatures.

Air was supplied to each unit by means of a 30 mm gas dispersion tube. Since adequate dissolved oxygen levels were readily obtained, the air rate was adjusted at a minimum to maintain a completely mixed condition.

Feed for the units was prepared from 2 parts Muskegon raw sewage and 3 parts Warren pulp and paper wastewater. Feed volumes of 3.5, 1.7 and 1.65 liters were added daily to the 2, 4 and 6-day units, respectively.

Evaporation loss and temperature were checked daily, while other paramaters such as, dissolved oxygen, pH, BOD, settleable solids, total suspended solids and volatile suspended solids were checked at least twice per week. BOD and solids of mixed liquor and final (settled) effluent were made. Sedimentation was done in an Imhoff cone with settleable solids volume being recorded after 30 minutes. The supernatant was siphoned off after one hour as final effluent for analysis.

Average weekly results are listed in Tables 10 and 11 for summer and winter operations, respectively. Table 12 gives the total chemical analyses on a typical feed, mixed liquor, and final effluent of the aerated lagoon treatability studies.

For design purposes the following parameters were determined: oxygen uptake rate, alpha factor and oxygen transfer efficiency. Oxygen-uptake rate is a measure of the oxygen utilization of the biomass (MLSS). The alpha factor is the ratio of the overall transfer coefficient, K_La (20°C), of the waste to that of water. Oxygen transfer efficiency is the percentage of oxygen supplied that is absorbed by the bulk liquid.

The oxygen uptake rate test was conducted in a 500 ml Erlenmeyer flask. Dissolved oxygen depletion as a function of time was measured with a dissolved oxygen meter, while the mixed liquor was being agitated by a magnetic stirrer. The atmosphere was sealed off during the tests in order to eliminate

TABLE 10: WEEKLY ANALYSES-SUMMER AERATION UNITS

Waste-water	Param-eter / Wk.	2 Days Detention					4 Days Detention					6 Days Detention				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Feed	TSS	413	423	505	503	362	413	423	505	503	362	413	423	505	503	362
	VSS	236	214	263	243	159	263	214	263	243	159	263	214	263	243	159
	BOD	309	127	213	226	171	309	127	213	226	171	309	127	213	226	171
	pH	8.5	8.3	8.4	8.4	7.4	8.5	8.3	8.4	8.4	7.4	8.5	8.3	8.4	8.4	7.4
Mixed Liquor	Temp.(°C)	20.5	21	21	21	21	20.5	21	21	21	21	20.5	21	21	21	21
	DO	5.9	7.9	6.9	-	8.0	6.4	7.7	6.9	-	8.2	6.5	7.4	4.4	-	8.2
	pH	8.3	8.2	8.4	8.4	8.1	8.3	8.3	8.4	8.4	8.2	8.4	8.3	8.4	8.5	8.3
	Set.S.(ml/l)	7	38	14	12	11	8	15	9	7	8	9	14	9	6	7
	TSS	550	491	436	425	312	520	566	487	348	447	427	606	489	425	415
	VSS	250	281	220	188	168	224	277	221	146	206	181	275	205	190	182
	BOD	-	-	-	117	126	-	-	-	62	124	-	-	-	75	129
Settled Effluent	TSS	67	77	116	32	70	78	92	104	18	33	62	64	60	48	47
	VSS	26	35	48	16	31	33	35	46	12	16	22	33	36	26	22
	BOD	32	14	24	11	27	28	14	26	11	26	19	15	19	12	34
	BOD Red.(%)	90	89	89	95	84	91	89	88	95	85	94	88	91	95	80
	TSS Red.(%)	84	82	77	94	81	81	78	79	96	91	85	85	88	91	87

Note: Unless otherwise noted, results in milligram per liter (mg/l)

TABLE 11: WEEKLY ANALYSES-WINTER AERATION UNITS

Wastewater	Parameter / Wk.	2 Days Detention					4 Days Detention					6 Days Detention				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Feed	TSS	413	423	505	503	362	413	423	505	503	362	413	423	505	503	362
	VSS	236	214	263	243	159	236	214	263	243	159	236	214	263	243	159
	BOD	309	127	213	226	171	309	127	213	226	171	309	127	213	226	171
	pH	8.5	8.3	8.4	8.4	7.4	8.5	8.3	8.4	8.4	7.4	8.5	8.3	8.4	8.4	7.4
Mixed Liquor	Temp.(°C)	8	7	6	6	6	8	7	6	6	6	8	7	6	6	6
	DO	8.0	10.2	6.0	-	11.3	8.7	10.4	7.5	-	11.3	9.0	10.3	8.0	-	10.9
	pH	8.3	8.3	8.1	8.4	8.2	8.3	8.3	8.1	8.3	8.2	8.3	8.3	8.2	8.3	8.2
	Set.S.(ml/l)	26	58	23	12	21	18	40	22	12	19	13	25	20	14	20
	TSS	668	675	497	428	479	608	607	574	523	450	524	601	565	462	502
	VSS	440	407	252	238	258	277	365	317	284	241	238	349	324	230	281
	BOD	-	-	-	138	182	-	-	-	130	127	-	-	-	123	169
Settled Effluent	TSS	209	105	180	132	138	127	106	212	102	146	231	61	116	58	138
	VSS	93	45	60	54	60	53	46	92	32	65	82	38	48	36	60
	BOD	119	32	70	44	55	57	32	68	36	47	43	32	44	27	33
	BOD Red.(%)	61	75	67	81	68	82	75	68	84	73	86	75	79	88	81
	TSS Red.(%)	49	75	64	74	62	69	75	58	80	60	44	86	77	89	62

Note: Unless otherwise noted, results in milligram per liter (mg/l)

TABLE 12: AERATED LAGOON CHEMICAL ANALYSES

Wastewater	Phosphate as P	Alkalinity	Chloride	Phenol	Cyanide	Hexane Soluble	Ammonia Nitrogen	Organic Nitrogen	Total Nitrogen	Sodium	Potassium	Nickel	Iron	Chromium	Zinc	Copper	Magnesium	Calcium	Dissolved Solids
Feed (Raw sewage plus Warren Waste	0.16	294		0.146	0.031	34	6.00	12.00	18.00	125.0	6.9	0.107	1.071	0.266	0.288	0.05	12.00	330.4	832
Mixed Liquor																			
2-Day Warm				0.02	0	10			12.00	119.6	5.6	0.107	1.372	0.936	0.480	0.05	12.50	110.6	
4-Day Warm	0.33					12			13.65										
6-Day Warm									12.45										
2-Day Cold									7.21	118.0	5.6	0.096	1.157	0.530	0.400	0.05	12.00	200.0	
4-Day Cold	0.03								12.42										
6-Day Cold	0.16																		
Filtered Effluent																			
2-Day Warm	0.57	208	163				0.35	2.65	3.00	105.5	5.3	0.004	0.240	0.065	<.001	<.005	13.00	121.9	575
4-Day Warm	0.96	196	152				0.52	5.73	6.25										571
6-Day Warm	0.77	198	160				1.25	2.13	3.38										587
2-Day Cold	0.29	196	138				4.40	2.60	7.00	105.5	5.3	0.096	0.257	0.132	<.001	<.005	12.00	118.1	551
4-Day Cold	0.36	194	193				4.25	2.63	6.88										660
6-Day Cold	0.44	196	154				3.85	2.10	5.75										561

Notes: 1. Feed represents 2 parts raw sewage plus 3 parts paper mill waste taken 4/23/70 at Muskegon.

2. Unless otherwise noted, results in milligram per liter (mg/l).

the transfer of atmospheric gases into the liquid. Uptake rates for high and low temperatures are tabulated in Table 13.

The alpha factor determination was conducted in a 2-liter jar. Air was supplied by a 30 mm gas dispersion tube while the liquid was slowly agitated by a magnetic stirrer. A rotameter metered the air flow rate. The liquid was first de-oxygenated with sodium sulfite and cobalt chloride as a catalyst. Dissolved oxygen concentrations (C_t) were taken at frequent intervals and the overall transfer coefficient (K_La) determined from the slope of (C_s-C_t) vs Time on semi-log paper. The saturation dissolved oxygen concentration is noted as C_s. The K_La was then adjusted to 20°C by the following relationship.

$$K_La\ (20°C) = K_La/1.02^{(T-20)}, \text{ where } T = \text{Temperature in } °C.$$

K_La (20°C) for tap water was obtained similarly. Alpha factors were determined on a typical feed and mixed liquors, at high and low temperatures, to check for any variation. Results are given in Table 14. Oxygen transfer efficiency is defined by the following:

$$\text{Oxygen Transfer Efficiency} = \frac{O_2 \text{ absorbed} \times 100}{O_2 \text{ supplied}}$$

Oxygen absorbed at zero dissolved oxygen level of the bulk liquid is calculated from the relationship:

$N = K_La\ (C_s)\ (8.34)\ V$, where: N is the O_2 absorbed per unit time, C_s is the O_2 saturation concentration of the wastewater, and V is the volume of the liquid.

In performing the oxygen transfer tests, the oxygen (air) supply was measured with a rotameter and converted to units consistent with N. Tests were run in a 2-liter jar at air flow rates of 1.5, 3.5, 3.5 and 7.5 scfh (standard cubic feet per hour) which correspond to 35, 83, 130, and 177 scfm per 1000 cf (standard cubic feet per minuteper 1000 cubic feet). Oxygen transfer efficiency vs air supply rate is illustrated in Figure 1.

The BOD reaction rate constant of the feed and settled effluent was determined by the Difference Method and the use of Theriault Tables. BOD's for 2, 4, 6, 8 and 10 days were used. Seed for the BOD tests were obtained from a local sewage treatment plant.

TABLE 13: AERATED LAGOON OXYGEN UPTAKE RATES

Wastewater	MLVSS (mg/l)	Uptake Rate (mg/l/hr)	Oxygen Uptake Rate mg/l/hr/gm VSS	Temp (°C)
2 Day-Warm	188	7.2	19.2	24
4 Day-Warm	213	3.6	16.1	24
6 Day-Warm	202	3.0	14.8	24
4 Day-Cold	172	0.27	0.8	5
6 Day-Cold	180	0.26	0.7	9

TABLE 14: AERATED LAGOON ALPHA FACTORS

Wastewater	Alpha	Temp (°C)
Feed (Raw sewage & paper waste)	.88	22
Mixed Liquor:		
2 Day-Warm	.85	24
4 Day-Warm	.93	21
2 Day-Cold	.84	11
6 Day-Cold	.82	7

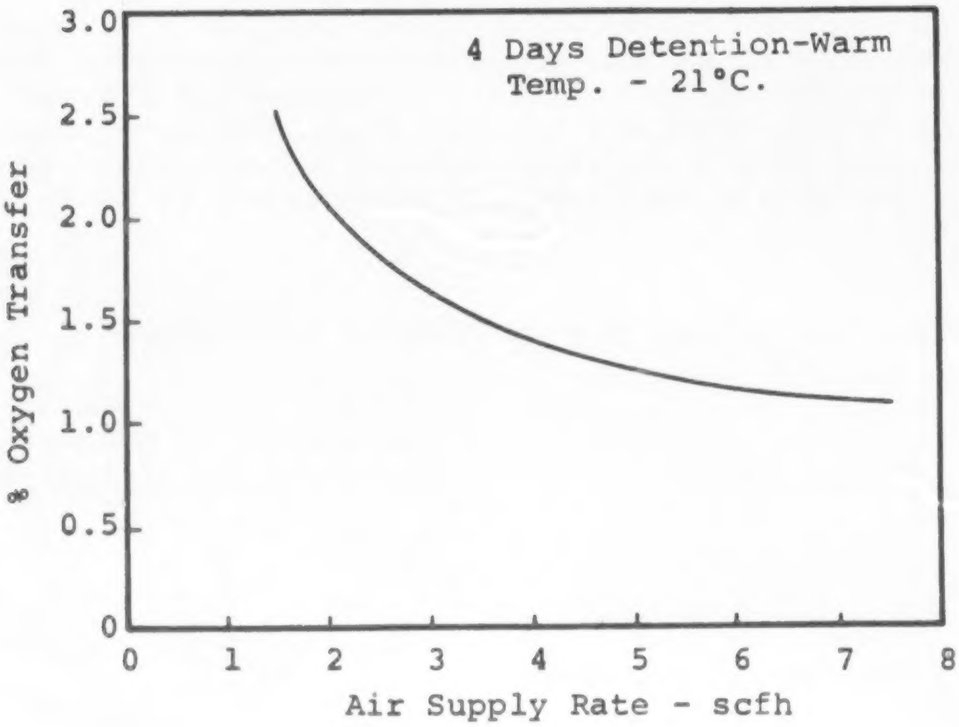


FIGURE 1: AERATED LAGOON OXYGEN TRANSFER TEST

Permeability Test

A 2-inch I.D. column was used for permeability tests. A constant water head was maintained above a 1-foot depth of Muskegon area sand. The filtrate rate was recorded against time and illustrated in Figure 2. The standard coefficient of permeability, K_s, was determined from the following relationship:

$$K_s = \frac{QL}{A(dh)}$$, where:

Q is the discharge rate
L is the sand depth
A is the surface area
dh is the hydraulic head

The sand media was considered to approach a "sealed" condition when the filtrate rate had approached a steady state. The solids required to impregnate the sand media were then calculated from a material balance of the input and filtrate. The solids analyses are summarized in Table 15.

TABLE 15. LAGOON BOTTOM PERMEABILITY TESTS

Wastewater	Total Suspended Solids-mg/l	Volatile Suspended Solids-mg/l
Feed	340	176
Filtrate (to 1 1/2 hours)	3	3
Filtrate Composite (1 1/2 hours - 24 hours)	8	8
Filtrate Composite (24 hours - 48 hours)	4	4

Sand permeability after impregnation by solids was determined by the falling head permeability test in the 2-inch column. The equation for permeability, k, is:

$$k = \frac{L}{dt} \log_{10} \frac{h_o}{h_1}$$, where:

h_o is the hydraulic head at start of test
h_1 is the head after time t_1, and
$dt = (t_i - t_o)$

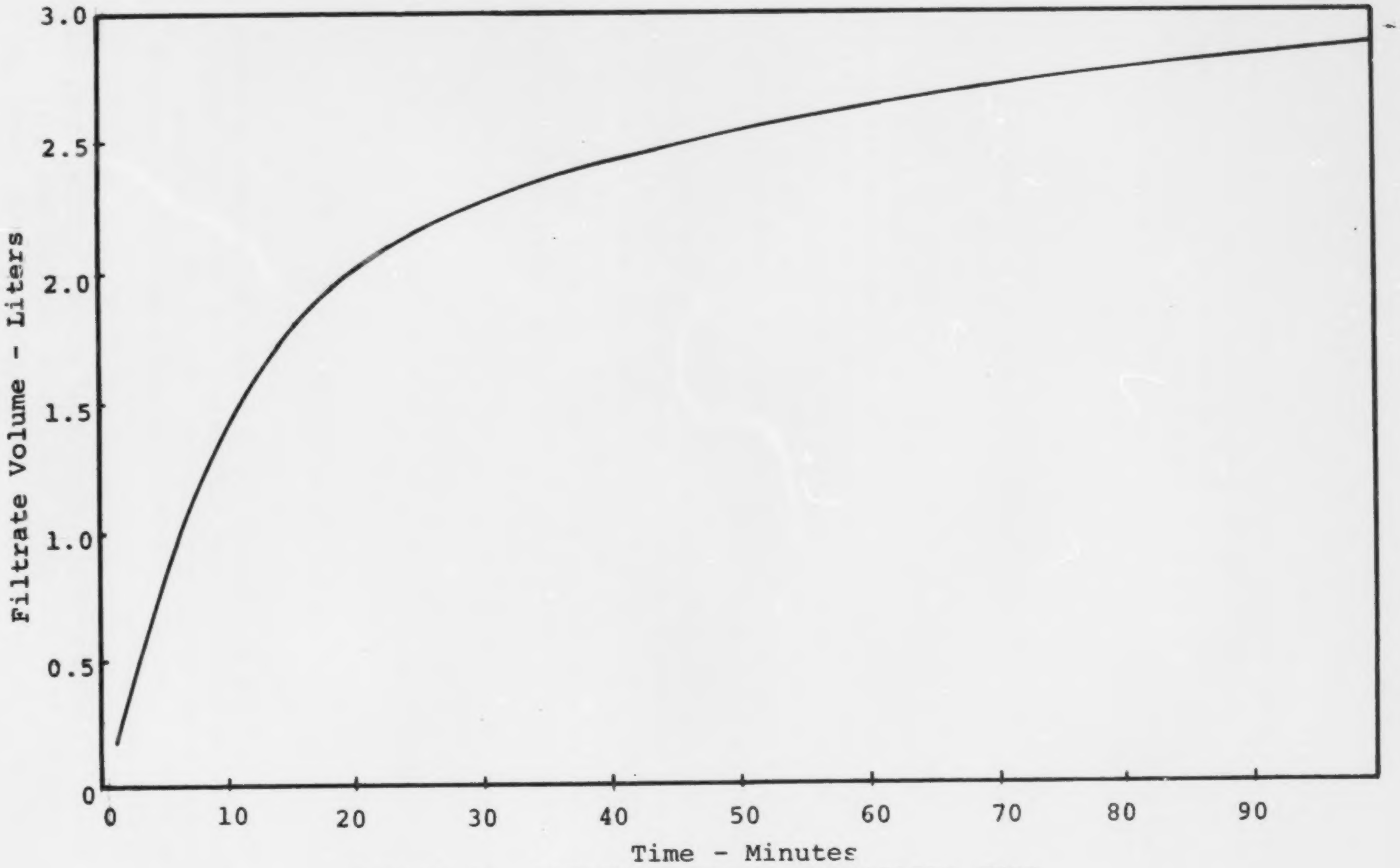


FIGURE 2: LAGOON BOTTOM PERMEABILITY TEST

Sludge Gas Production Test

Accumulated waste sludge from the pilot units was concentrated by repeated decantation over a period of several weeks and used for this test. Gas production rate from enclosed aspirator bottle was measured by liquid displacement in a graduated column. Figure 3 illustrates the gas production over the first 70 hours.

Column Filtration Tests

Column filtration tests were conducted to study the removal of nutrients, color, and BOD from settled pond effluent. For this test, treated waste from the lagoon units was allowed to settle for over 30 days. The supernatant was then filtered through 6-inch O.D. columns filled with Muskegon sand,with approximately 6 inches of Muskegon turf on top. Each column was washed with approximately 5 gallons of distilled water prior to the start of test runs.

Hydraulic loading rates of 1.5 and 4.5 inches per week of lagoon effluent were tested on 5 ft. and 10 ft. high columns. The feed was added three times per week at a third of the loading rates. In addition, 1/2-inch of rainwater (distilled water) was added once a week to each of the four columns. Complete results for 4 weeks are tabulated in Table 16.

Discussion of Results

Aerated Lagoons

Table 17 is a summary of the aerated lagoon studies. BOD and solids reductions are tabulated for each unit with their corresponding loading factors. The pond loadings, assuming a 10 foot depth, range from 1390 to 2950 as pounds of BOD per day per acre.

Table 17 shows that among the summer units, detention times and loading factors over the range tested had only slight effect on BOD and solids reductions. Lower loadings

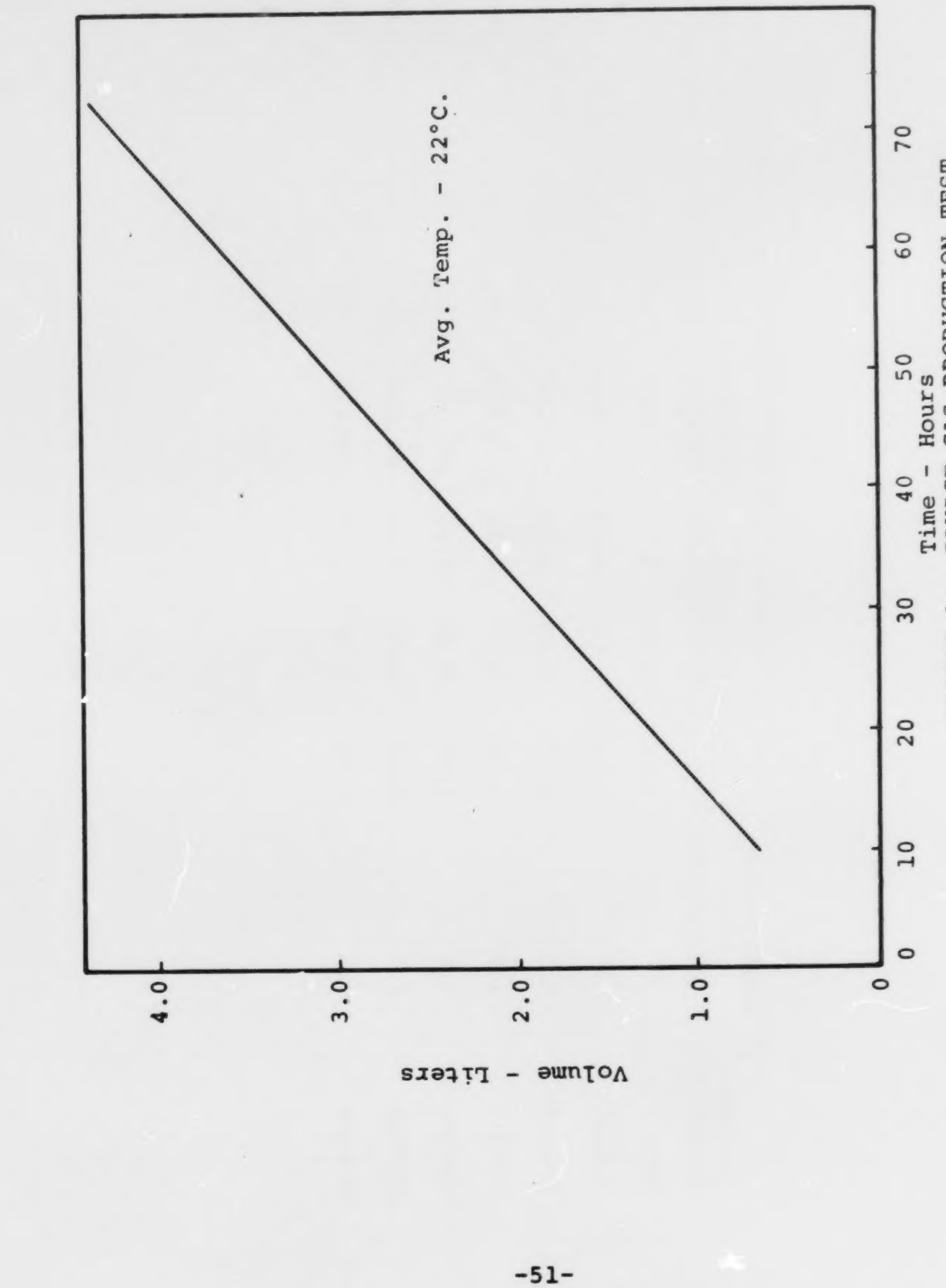


FIGURE 3: SLUDGE GAS PRODUCTION TEST

TABLE 16: SUMMARY-SOIL COLUMN FILTRATION TESTS

Column (Diameter)	Application Rate (inches/week)	Average Values						
		Nitrogen - mg/l			Phosphate (P)mg/l	Color Units	pH Units	Specific Conductance micromhos/cm
		Ammonia	Nitrate	Total				
Feed	-	4.20	0.63	6.25	1.890	450	8.2	850
5-Foot	1.5	1.19	0.36	4.54	0.007	<5	8.0	314
5-Foot	2.5	0.20	0.09	1.95	<0.002	<5	8.3	140
5-Foot	4.5	1.33	3.75	2.92	0.015	<5	8.0	400
10-Foot	1.5	1.50	0.55	3.23	0.056	55	8.1	375
10-Foot	2.5	0.18	0.08	2.10	<0.002	<5	8.2	220
10-Foot	4.5	1.63	0.56	3.65	0.015	<5	7.9	300

TABLE 17: SUMMARY-LABORATORY AERATED LAGOON TESTS

	Loading Factor		Reductions-% (5 weeks average)	
	lb. BOD/day/lb. VSS	lb/BOD/day/1000 cf	Total Suspended Solids	BOD
2 Days-Warm	0.47	6.8	84	89
4 Days-Warm	0.24	3.4	85	90
6 Days-Warm	0.17	3.2	87	90
2 Days-Cold	0.33	6.8	65	70
4 Days-Cold	0.18	3.4	68	76
6 Days-Cold	0.12	3.2	72	82

produced more significant improvements in both BOD and solids reductions for the winter units.

The highest loading (2 days detention) for the summer unit gave better performance than the lowest loading (6 days detention) for the winter unit.

Oxygenation Parameters

The oxygen uptake rate per unit solids (Table 13) was lower at longer detention time - 14.8 compared with 19.2 mg/l per hour per gm VSS at 2-day detention. This may be due to the more stable condition of bacterial growth existing in units with 6-day detention. At a winter temperature of approximately 5°C the uptake rate was only 0.8 mg/l per hour per gm VSS.

The alpha factor of the feed (Table 14) was determined to be 0.88. Alpha factors of the mixed liquor at high temperature was slightly different from the feed; but at low temperatures the results was slightly lower. The magnitude and trend of the values are reasonable.

Oxygen transfer efficiency varied with the air supply rate from a high of 2.5% at 1.5 scfh (35 scfm/1000cf) to 1.2% at 7.5 scfhs (177 scfm/1000cf). Other factors that may influence the efficiency under field conditions are: method of aeration, temperature, depth and the overall geometry of the lagoon.

Reaction Rate Constant

Reaction rate constants, k_1 (to the base 10), were determined on a typical feed and settled aerated lagoon effluent at summer and winter temperatures. The k_1-values for the feed were 0.06 and 0.02 for 20°C and 5°C, respectively. Values for the settled effluent were 0.05 and 0.09 for 20°C and 5°C, respectively. The low k_1 values indicate a slow initial rate of bio-oxidation.

Permeability Tests

The standard coefficient of permeability, K_s, was determined to be 0.15 gpd per sq. ft. per ft. of depth.

After a period from 1.5 hours to approximately 24 hours, the filtration rate was fairly constant at about 2.5 ml/min., which was approximately 1.4 percent of the initial rate. At this point (24 hours) the sand was considered to approach sealed conditions. The solids required to impregnate the sand media were calculated to be 0.2 lb. per sq. ft. per ft. of depth. The filtration rate between 24 and 48 hours decreased to approximately 1.5 ml/min.

The column was allowed to filter continously for 4 days, after which time the permeability was determined by the varying head test to be 2.3 feet per day.

Sludge Gas Production Tests

Gas production rate (Figure 3) at room temperature from concentrated waste sludge averaged 0.65 ml/hr/gm of solids over a period of 70 hours. Thereafter, production rate tapered off and stopped completely after approximately 2 weeks.

Before testing, the solids concentration was 11.9% with 60.7% fixed and 39.5% volatile solids. The solids concentration was reduced to 10.0% after the sludge was stabilized, andconsisted of 65.6% fixed and 34.4% volatile solids. Total gas produced over the 2 weeks period was 8420 ml, or 842 ml/gm VSS removed.

Column Filtration Tests

Initially the hydraulic loadings to the filtration columns were 1.5 and 2.5 inches per week of supernatant feed. Thereafter, the loading rates were 1.5 and 4.5 inches per week. Generally, column filtration studies showed a reduction of ammonia nitrogen, nitrate nitrogen and total nitrogen. The trend was about 50% ammonia and total nitrogen reductions, with only a slight reduction of nitrate. The 10-foot column was only slightly more efficient than the 5-foot columns in removing nitrogen.

Phosphate was reduced from an average of 1.9 mg/l to less than 0.09 mg/l. The 10-foot columns demonstrated a greater degree of phosphate removal. Color was reduced from 450 units to less than 5 units in three columns. The residual color observed in one 10-foot column was probably due to coloration from the sand media. The soil in that particular column was obtained from a different location.

The average dissolved salt (as measured by Specific Conductance) reduction was 62%. Both columns demonstrated approximately the same degree of reduction. Average evaporation losses for the third and fourth week were: 32 percent from the 5-foot column and 52% from the 10-foot columns.

Chlorine Demand

Two sets of measurements were taken on chlorine demand using 30-minute contact time. The first tests, Series A, on May 27, 1970 indicated a demand of less than 8.2 mg/l. This represents effluent directly from the pilot units with little time for stabilization. The second tests, Series B, were conducted on June 20, 1970 and gave a chlorine demand of less than 4.6 mg/l. This decrease in demand is due to stabilization of the pilot plant effluent after storage in a stimulated lagoon. The results of the tests are given in Table 18.

TABLE 18: CHLORINE DEMAND

Test	Chlorine Dose (mg/l)	Chlorine Residual (mg/l)	Total Coliform (org./100 ml.)
A-1	5.0	0	3,000
A-2	10.0	1.3	<10
B-1	4.0	0	<10
B-2	6.0	1.4	<10

Algae Growth

Pilot plant effluent both filtered and unfiltered was seeded with algae and allowed to remain on the laboratory bench under a fluorescent lamp. Within three days algae began to develop in the filtered sample and within five days in the unfiltered sample. Heavy growth occurred in both samples by the end of two weeks. Quantitative data was not collected because limited funds and time prevented designing an experimental arrangement capable of producing meaningful quantitative data.

SECTION VII

SIMULATION MODEL

Introduction

The objectives of the simulation model study were: (1) to estimate the lagoon storage requirements under various climatological conditions and for certain rates of irrigation and (2) to evaluate the levels of selected water quality parameters within the water in the storage lagoons.

Storage requirements need to be evaluated so that a sufficient volume is available for retaining the treated wastewater when irrigation is not feasible. The quality of the stored water was estimated utilizing mathematical relationships for Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), and Suspended Solids (SS). Of particular interest was the length of time during the "spring ice break-up" before aerobic conditions would be re-established in the storage lagoons.

Climatological Input Data

The major external input to the model was the climatological data which provided the framework within which the simulation of irrigation and evolution of water quality parameters within storage lagoons occurred.

Climatological data in punched card form (later transferred to magnetic tape) were obtained for the Muskegon, Michigan, Weather Station from the National Weather Bureau Records at Asheville, North Caroline. The information included the maximum daily temperature,minimum daily temperature, daily precipitation, and daily measurement of snow and ice cover for the years 1948 to 1969, inclusive. This range of years, twenty-two in all, was considered sufficient for the long-range simulation envisioned in the study. In the model, only one data modification took place. This was the derivation of average daily temperatures as the mid-point of the range between the daily maxima and minima.

The Model

The simulation model consists of two major components: a quality model oriented to the study of major water quality parameters (BOD, DO, SS) in the storage lagoons, and a quantity model oriented to the study of storage requirements and allowable irrigation under specified operating rules. The model, itself, with both components, as mentioned above, is schematically represented on Figure 4. The partitioning shown in Figure 4 represents the three operational parts of the model: (1) generation of input parameters to daily operation, (2) the simulation of daily operations, and (3) the statistical analysis of daily operations over the time period of study.

The generation of daily inputs includes fixed inputs into the storage lagoons of treated wastewater from the aerated lagoons having the following quality parameter values: BOD=125 mg./l., DO=2 mg./l., SS=500 mg./l., Q-32 MGD. Variable daily inputs consist of average daily temperature, daily precipitation, and height of snow and ice cover made available from U.S. Weather Bureau Records as discussed earlier. Also, initial storage lagoon water quality parameters (BOD-20 mg./l., DO=6 mg./l., temperature of water-65°F, and initial storage of 2540 million gallons) are assumed at the beginning of the simulated period of study and are updated with daily operations.

Daily operations consist of: (1) a decision regarding the quantity to be irrigated (including the possibility of zero irrigation) and the updating of quantity and quality of wastewater contained within the storage lagoons.

The quantity to be withdrawn from the storage lagoons is based upon the relationship in Eq. (1): $Q = R + E - P$, where:

Q = amount withdrawn (in.)*
R = maximum allowable irrigation rate (in.)**
E = Evaporation (in.)
P = Precipitation (in.)

*Quantity irrigated in inches is internally converted to MG (million gallons) to conform to volume calculations elsewhere.

**Maximum allowable irrigation rate is governed by wastewater irrigation requirements plus an allowance for precipitation based on average weekly precipitation of 0.62".

The allowance for evaporation is computed by Eq. (2): $E = 0.013\ F\ (T_{avg} - 32)$, where:

E = evaporation (in.)
F - seasonal atmospheric constant
T_{avg} = average daily temperature (°F.)

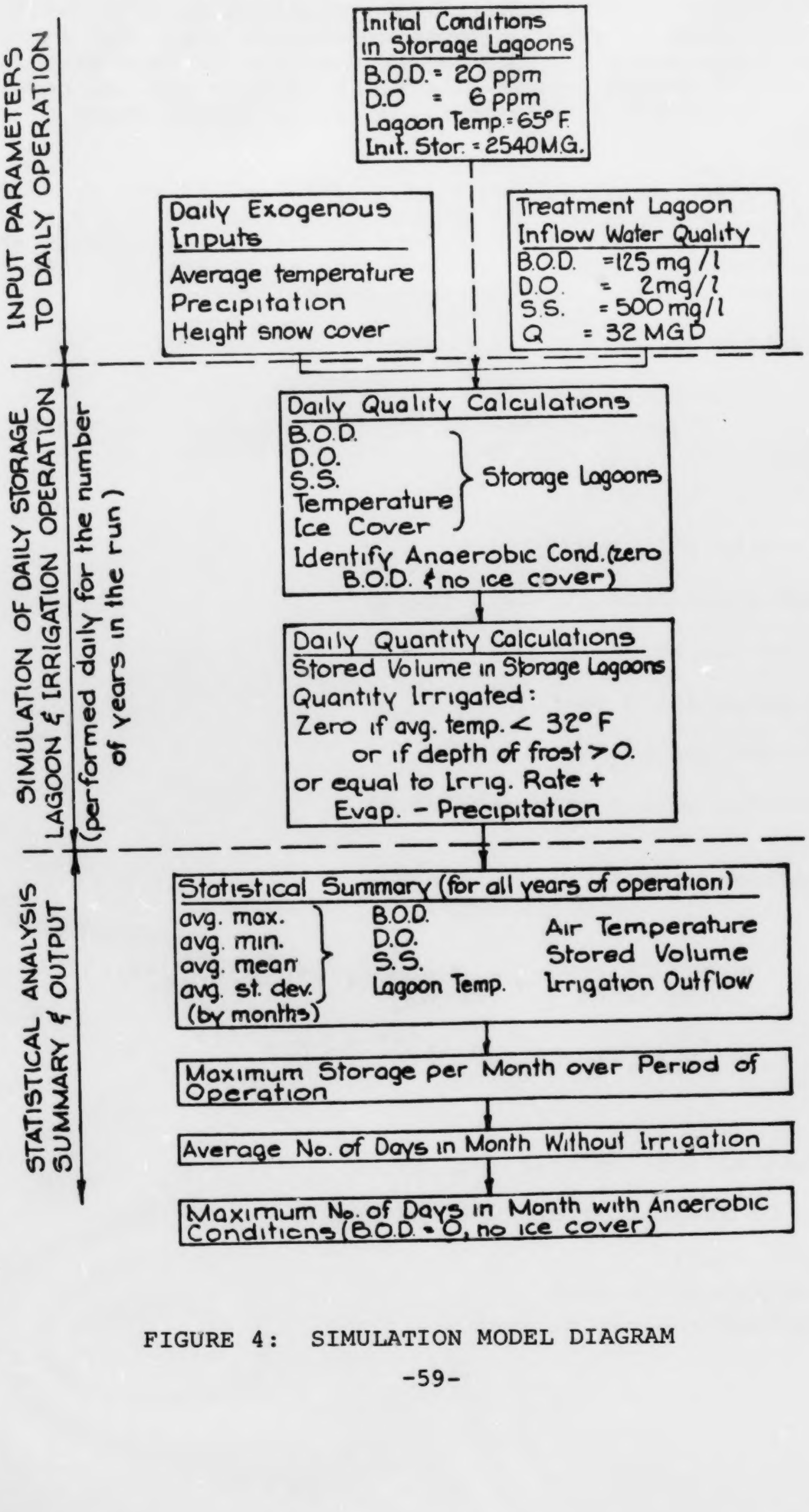

INPUT PARAMETERS TO DAILY OPERATION
Initial Conditions in Storage Lagoons
B.O.D. = 20 ppm
D.O = 6 ppm
Lagoon Temp. = 65° F
Init. Stor. = 2540 M.G.
Daily Exogenous Inputs
Average temperature
Precipitation
Height snow cover
Treatment Lagoon Inflow Water Quality
B.O.D. = 125 mg/l
D.O. = 2 mg/l
S.S. = 500 mg/l
Q = 32 MGD
SIMULATION OF DAILY STORAGE LAGOON & IRRIGATION OPERATION
(performed daily for the number of years in the run)
Daily Quality Calculations
B.O.D.
D.O.
S.S.
Temperature
Ice Cover
Storage Lagoons
Identify Anaerobic Cond. (zero B.O.D. & no ice cover)
Daily Quantity Calculations
Stored Volume in Storage Lagoons
Quantity Irrigated:
Zero if avg. temp. < 32° F
or if depth of frost > 0.
or equal to Irrig. Rate + Evap. - Precipitation
STATISTICAL ANALYSIS SUMMARY & OUTPUT
Statistical Summary (for all years of operation)
avg. max.
avg. min.
avg. mean
avg. st. dev.
(by months)
B.O.D.
D.O.
S.S.
Lagoon Temp.
Air Temperature
Stored Volume
Irrigation Outflow
Maximum Storage per Month over Period of Operation
Average No. of Days in Month Without Irrigation
Maximum No. of Days in Month with Anaerobic Conditions (B.O.D. = 0, no ice cover)

FIGURE 4: SIMULATION MODEL DIAGRAM

Under certain conditions irrigation is prohibited (i.e., is equal to zero). These conditions are: (1) if average temperature for the day in question is less than 32°F, (2) if frozen ground exists, or if snow and ice cover exists. These decision conditions can be easily changed if necessary.

After updating the volume contained in the storage lagoons (accounting for the amount withdrawn and the daily inflow of 32 million gallons), the quality parameters in the storage lagoons are then updated using equations (3) through (5) for BOD, DO, and temperature, respectively.

BOD Equation 3):

$$L_b = \left[L_a - \frac{d}{K_1+K_3}\right] e^{-(K_1+K_3)t} + \frac{d}{K_1+K_3} \quad \text{, where}$$

L_a = initial BOD, (mg/l)

L_b = BOD after time 't' days (mg/l)

t = time (days)

K_1 = deoxygenation coef.

K_3 = deposition coef.

d = benthal demand rate (mg/l/day)

DO (Equation 4):

$$D_b = \frac{K_1}{K_2-K_1-K_3}\left[L_a - \frac{d}{K_1+K_3}\right]\left(e^{-(K_1+K_3)t} - e^{-K_2 t}\right) + \frac{K_1}{K_2}\left[\frac{d}{K_1+K_3} - \frac{p}{K_1}\right]\left(1 - e^{-K_2 t}\right) + D_a e^{-K_2 t} \quad \text{, where}$$

D_a = initial D.O. deficit (mg/l)

d_b = D. O. deficit after time 't' (mg/l)

t = time (days)

K_1 = deoxygenation coef.

K_2 = surface reaeration coef.

K_3 = deposition coef.

p = photosynthesis oxygenation rate (mg/l/day)

d = benthal demand rate (mg/l/day)

Lagoon Temperature (Equation 5):

$$T_w = \frac{f A T_a + Q T_i}{f A + Q} \quad \text{, where}$$

Tw = lagoon temperature (°C)

f = proportionality factor (wind, solar radiation, etc.)

Ta = air temperature (°C)

Q = inflow (MG)

Ti = inflow water temperature (°C)

A = surface area of lagoon (acres)

The daily operations are repeated for the period of study. Upon completion of the daily operations, a statistical summary is made in a manner such that an analysis is made for each month over the period of study to obtain a representative operation for each month of the year. (e.g., with 22 years of operations, a statistical summary is made for the 22 Januarys in question). This type of output enables one to identify directly the long-term seasonal characteristics of operation. Included in the monthly summary are mean, standard deviation, minimum, and maximum of selected parameters. In addition, the maximum number of days without irrigation and maximum number of days with critical anaerobic conditions are determined.

Simulation Results

Typical computer results for the 22 years of operation are presented in Table 19 for an average wastewater irrigation rate of 1.5" per week and an irrigation area of 9,470 acres. The computer output has been programmed to be self-explanatory.

TABLE 19: SIMULATION RESULTS
(IRRIGATION RATE = 1.5 IN./WK.)

```
NOTE: AVG.REPRESENTS AVG. OVER NO. OF YEARS STUDIED
LAGOON STORAGE LISTED IS WORKING VOLUME
TOTAL LAGOON STORAGE=WORKING VOL. +1100 M.G.
```

AVERAGE WEEKLY IRRIGATION RATE = 1.5 inches/wk.

```
 YEARS:1948 TO 1969          MONTH:  1        NO. OF DAYS IN MONTH:, 31

          LAGOON     LAGOON     LAGOON     LAGOON      TOTAL    LAGOON      AIR
          OUTFLOW    STORAGE    D.O.       B.O.D.    SUS.SOL.   TEMP.      TEMP.
AVG.      M.G.D.     M.G.       MG./L.     MG./L.     1000T.     C.         F.

MIN.       0.0       1059.0     0.00       32.51      256.0      4.0        8.9
MAX.      14.4       2006.7     0.23       38.27      258.0      4.8       39.4
MEAN       0.7       1531.0     0.03       35.67      257.0      4.2       24.1
STDEV      3.0        287.9     0.06        1.74        0.6      0.2        7.9

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH= 31

MAX. STORAGE FOR MONTH=  2432.0 M.G.
OCCURRED IN YEAR: 1948

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=     21.5 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 0.
```

```
 YEARS:1948 TO 1969          MONTH:  2        NO. OF DAYS IN MONTH:, 28

          LAGOON     LAGOON     LAGOON     LAGOON      TOTAL    LAGOON      AIR
          OUTFLOW    STORAGE    D.O.       B.O.D.    SUS.SOL.   TEMP.      TEMP.
AVG.      M.G.D.     M.G.       MG./L.     MG./L.     1000T.     C.         F.

MIN.       0.0       2038.7     0.00       38.40      258.0      4.0       11.3
MAX.       7.3       2900.6     0.00       41.08      259.9      4.1       40.0
MEAN       0.4       2469.9     0.00       39.37      258.9      4.0       25.1
STDEV      1.6        262.4     0.00        0.81        0.6      0.0        7.4

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH= 28

MAX. STORAGE FOR MONTH=  3360.0 M.G.
OCCURRED IN YEAR: 1948

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=     10.9 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 0.
```

TABLE 19 (continued)

```
 YEARS:1948 TO 1969          MONTH:  3        NO. OF DAYS IN MONTH:, 31

         LAGOON    LAGOON    LAGOON    LAGOON     TOTAL    LAGOON     AIR
         OUTFLOW   STORAGE   D.O.      B.O.D.    SUS.SOL.  TEMP.     TEMP.
AVG.     M.G.D.     M.G.     MG./L.    MG./L.    1000T.     C.        F.

MIN.       0.0     2926.4     0.00      41.15     259.9      4.0      17.4
MAX.      67.7     3643.4     0.00      42.58     261.9      4.7      50.4
MEAN      11.1     3295.0     0.00      41.96     260.9      4.2      32.5
STDEV     23.3      214.5     0.00       0.44       0.6      0.2       8.5

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH= 27

MAX. STORAGE FOR MONTH=  4268.2 M.G.
OCCURRED IN YEAR: 1956

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=   343.2 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 0.


 YEARS:1948 TO 1969          MONTH:  4        NO. OF DAYS IN MONTH:, 30

         LAGOON    LAGOON    LAGOON    LAGOON     TOTAL    LAGOON     AIR
         OUTFLOW   STORAGE   D.O.      B.O.D.    SUS.SOL.  TEMP.     TEMP.
AVG.     M.G.D.     M.G.     MG./L.    MG./L.    1000T.     C.        F.

MIN.       0.0     3005.5     0.00      24.19     262.0      4.5      31.2
MAX.      95.5     3650.0     0.00      42.62     263.9      7.6      61.9
MEAN      48.0     3345.9     0.00      36.64     263.0      5.8      45.3
STDEV     42.1      186.1     0.00       6.98       0.6      1.0       8.2

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH= 13

MAX. STORAGE FOR MONTH=  4802.1 M.G.
OCCURRED IN YEAR: 1950

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=  1438.9 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 15
OCCURRED IN YEAR: 1948
```

TABLE 19 (continued)

```
 YEARS:1948 TO 1969            MONTH:  5        NO. OF DAYS IN MONTH:, 31

         LAGOON   LAGOON    LAGOON    LAGOON     TOTAL    LAGOON     AIR
         OUTFLOW  STORAGE   D.O.      B.O.D.   SUS.SOL.   TEMP.     TEMP.
AVG.     M.G.D.    M.G.     MG./L.    MG./L.    1000T.     C.        F.

MIN.       0.0    1990.1    0.00      16.82     264.0      7.7      41.5
MAX.     113.4    3044.5    5.81      23.63     266.0     12.4      69.9
MEAN      66.3    2509.0    2.70      19.28     265.0     10.1      55.7
STDEV     47.6     312.7    2.07       1.98       0.6      1.4       7.5

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH= 11

MAX. STORAGE FOR MONTH=  4583.6 M.G.
OCCURRED IN YEAR: 1950

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=  2054.3 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER=  9
OCCURRED IN YEAR: 1950


 YEARS:1948 TO 1969            MONTH:  6        NO. OF DAYS IN MONTH:, 30

         LAGOON   LAGOON    LAGOON    LAGOON     TOTAL    LAGOON     AIR
         OUTFLOW  STORAGE   D.O.      B.O.D.   SUS.SOL.   TEMP.     TEMP.
AVG.     M.G.D.    M.G.     MG./L.    MG./L.    1000T.     C.        F.

MIN.       0.0     764.3    5.93      13.88     266.1     12.5      53.0
MAX.     121.2    1985.4    7.88      16.71     268.0     18.4      77.8
MEAN      72.7    1340.5    7.04      15.22     267.0     15.5      65.6
STDEV     50.5     370.7    0.60       0.89       0.6      1.8       6.7

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH=  9

MAX. STORAGE FOR MONTH=  3563.3 M.G.
OCCURRED IN YEAR: 1950

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=  2180.2 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 0.
```

TABLE 19 (continued)

```
 YEARS:1948 TO 1969          MONTH:  7         NO. OF DAYS IN MONTH:, 31

        LAGOON    LAGOON    LAGOON    LAGOON     TOTAL    LAGOON      AIR
        OUTFLOW   STORAGE    D.O.     B.O.D.   SUS.SOL.   TEMP.      TEMP.
AVG.    M.G.D.     M.G.     MG./L.    MG./L.    1000T.      C.         F.

MIN.      0.0      105.4     7.55     12.32     268.1      18.2      60.4
MAX.    115.0      802.6     8.39     13.61     270.1      22.1      78.8
MEAN     53.5      365.6     8.03     13.00     269.1      20.3      70.2
STDEV    40.7      224.5     0.26      0.46       0.6       1.2       4.8

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH=  8

MAX. STORAGE FOR MONTH=  2509.0 M.G.
OCCURRED IN YEAR: 1969

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=  1658.6 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 0.


 YEARS:1948 TO 1969          MONTH:  8         NO. OF DAYS IN MONTH:, 31

        LAGOON    LAGOON    LAGOON    LAGOON     TOTAL    LAGOON      AIR
        OUTFLOW   STORAGE    D.O.     B.O.D.   SUS.SOL.   TEMP.      TEMP.
AVG.    M.G.D.     M.G.     MG./L.    MG./L.    1000T.      C.         F.

MIN.      0.0        0.1     7.66     12.14     270.1      19.1      58.6
MAX.    102.6      132.4     8.42     13.39     272.1      22.5      79.1
MEAN     35.1       39.3     8.08     12.79     271.1      20.7      68.9
STDEV    29.5       53.9     0.23      0.40       0.6       1.0       5.3

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH=  8

MAX. STORAGE FOR MONTH=  1195.8 M.G.
OCCURRED IN YEAR: 1950

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=  1088.1 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 0.
```

TABLE 19 (continued)

```
 YEARS:1948 TØ 1969            MØNTH:  9          NØ. ØF DAYS IN MØNTH:, 30

        LAGØØN    LAGØØN    LAGØØN    LAGØØN     TØTAL    LAGØØN     AIR
        ØUTFLØW   STØRAGE    D.Ø.     B.Ø.D.   SUS.SØL.   TEMP.     TEMP.
AVG.    M.G.D.     M.G.     MG./L.    MG./L.    1000T.      C.        F.

MIN.      0.0        0.0     7.01     12.80     272.2      14.9      46.8
MAX.     96.4      112.8     8.19     15.45     274.1      21.2      75.7
MEAN     31.6       23.6     7.67     13.98     273.2      18.1      61.5
STDEV    28.8       33.7     0.36      0.82       0.6       1.9       7.4

AVG. NUMBER ØF DAYS WITHØUT IRRIGATIØN FØR MØNTH= 10

MAX. STØRAGE FØR MØNTH=   320.0 M.G.
ØCCURRED IN YEAR: 1964

AVG. TØTAL MØNTHLY IRRIGATIØN (ØUTFLØW)=   948.3 M.G.

MAX. DAYS ANAERØBIC CØNDITIØNS WITH NØ ICE CØVER= 0.
```

```
 YEARS:1948 TØ 1969            MØNTH: 10          NØ. ØF DAYS IN MØNTH:, 31

        LAGØØN    LAGØØN    LAGØØN    LAGØØN     TØTAL    LAGØØN     AIR
        ØUTFLØW   STØRAGE    D.Ø.     B.Ø.D.   SUS.SØL.   TEMP.     TEMP.
AVG.    M.G.D.     M.G.     MG./L.    MG./L.    1000T.      C.        F.

MIN.      0.0        0.0     4.16     15.48     274.2       9.4      37.4
MAX.     91.4      115.6     7.05     19.22     276.2      16.0      66.7
MEAN     32.0       29.1     5.62     17.30     275.2      12.7      51.5
STDEV    29.0       34.7     0.89      1.13       0.6       1.9       7.8

AVG. NUMBER ØF DAYS WITHØUT IRRIGATIØN FØR MØNTH= 10

MAX. STØRAGE FØR MØNTH=   215.4 M.G.
ØCCURRED IN YEAR: 1954

AVG. TØTAL MØNTHLY IRRIGATIØN (ØUTFLØW)=   992.5 M.G.

MAX. DAYS ANAERØBIC CØNDITIØNS WITH NØ ICE CØVER= 0.
```

TABLE 19 (continued)

```
 YEARS:1948 TO 1969          MONTH: 11          NO. OF DAYS IN MONTH:, 30

        LAGOON    LAGOON    LAGOON     LAGOON      TOTAL    LAGOON     AIR
        OUTFLOW   STORAGE    D.O.      B.O.D.    SUS.SOL.   TEMP.     TEMP.
AVG.    M.G.D.     M.G.     MG./L.     MG./L.     1000T.      C.        F.

MIN.      0.0       12.8     0.70      19.21      276.3       4.6      24.0
MAX.     82.3      313.7     4.14      22.86      278.2      10.3      55.5
MEAN     24.3      121.2     2.30      21.16      277.2       7.2      39.3
STDEV    30.8       90.4     1.11       1.10        0.6       1.7       7.9

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH= 17

MAX. STORAGE FOR MONTH=    718.2 M.G.
OCCURRED IN YEAR: 1951

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=    728.0 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 10
OCCURRED IN YEAR: 1959


 YEARS:1948 TO 1969          MONTH: 12          NO. OF DAYS IN MONTH:, 31

        LAGOON    LAGOON    LAGOON     LAGOON      TOTAL    LAGOON     AIR
        OUTFLOW   STORAGE    D.O.      B.O.D.    SUS.SOL.   TEMP.     TEMP.
AVG.    M.G.D.     M.G.     MG./L.     MG./L.     1000T.      C.        F.

MIN.      0.0      240.7     0.00      23.34      278.3       4.0      14.0
MAX.     52.2     1046.4     0.65      32.78      280.3       5.2      44.2
MEAN      7.2      627.3     0.06      24.72      279.3       4.2      28.8
STDEV    16.6      247.2     0.17       2.87        0.6       0.4       7.6

AVG. NUMBER OF DAYS WITHOUT IRRIGATION FOR MONTH= 28

MAX. STORAGE FOR MONTH=  1472.6 M.G.
OCCURRED IN YEAR: 1969

AVG. TOTAL MONTHLY IRRIGATION (OUTFLOW)=    222.8 M.G.

MAX. DAYS ANAEROBIC CONDITIONS WITH NO ICE COVER= 0.
```

Discussion of Results

Salient quantity results are depicted in terms of maximum storage requirements in Figure 5 and in terms of average monthly outflow (i.e., amount irrigated) in Figure 6. Maximum storage requirements are conclusively (regardless of irrigation rate) found to occur in April and May before the start-up of spring irrigation. It should be noted that the storage volumes reported in Figure 5 are "working storage volumes", to these one must add 1100 MG of solids storage volume in order to determine the total lagoon storage requirements.

By referring to Figure 6, it is seen that maximum wastewater irrigation occurs April to July with the peak varying according to the irrigation rate. One should note that the constraints on irrigation are primarily climatological during the winter months and are primarily the availability of wastewater during the summer months. An additional part of the output of the simulation study was the maximum monthly storage requirements for each of the 22 years. This information was used as the basis in preparing Table 20 which reflects the frequency of maximum lagoon storage requirements.

TABLE 20: LAGOON STORAGE

	NO. OF YEARS, IN 22 YEARS, LAGOON STORAGE REQUIREMENTS EXCEEDED		
Average Irrigation Rate inches/wk.	3840 M.G. (4 mo. @ 32 MGD)	4320 M.G. (4.5 mo. @ 32 MGD)	4800 M.G. (5 mo. @ 32 MGD)
1.5	8	3	1
1.75	8	1	0
2.0	8	1	0
2.5	7	1	0

With regard to the water quality aspects of the simulation study, the results indicate that the quality values are generally independent of the rates of irrigation. The BOD level within the storage lagoons is estimated to range from about 12 to 43 mg./l., with DO levels ranging from 0 to about 8 mg./l. Based on the data generated, there would be a period of approximately three weeks after the "spring ice break-up" before aerobic conditions would be re-established in the storage lagoons. In the model, ice cover was assumed to exist between December 1 and April 15.

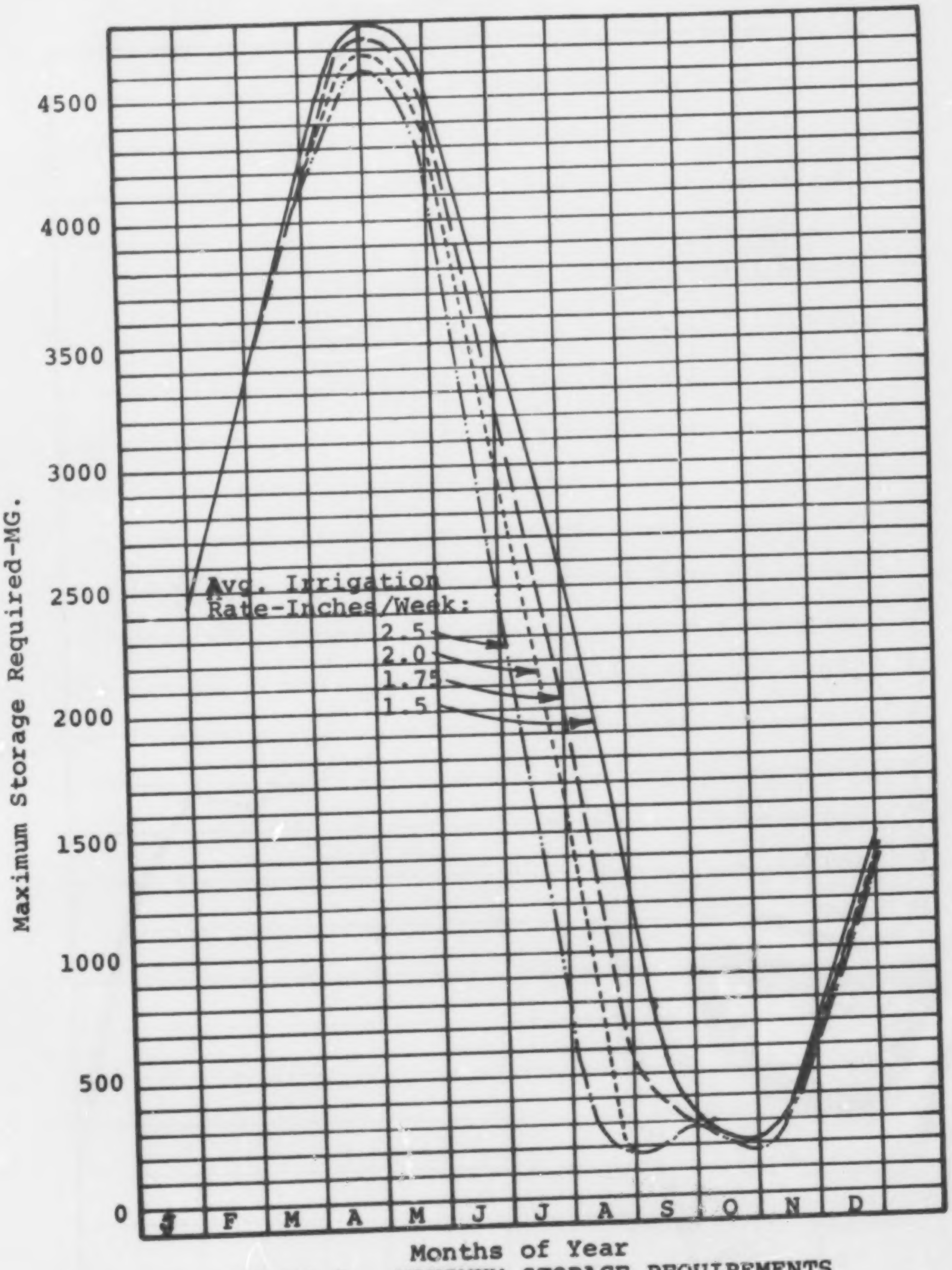


FIGURE 5: MAXIMUM STORAGE REQUIREMENTS

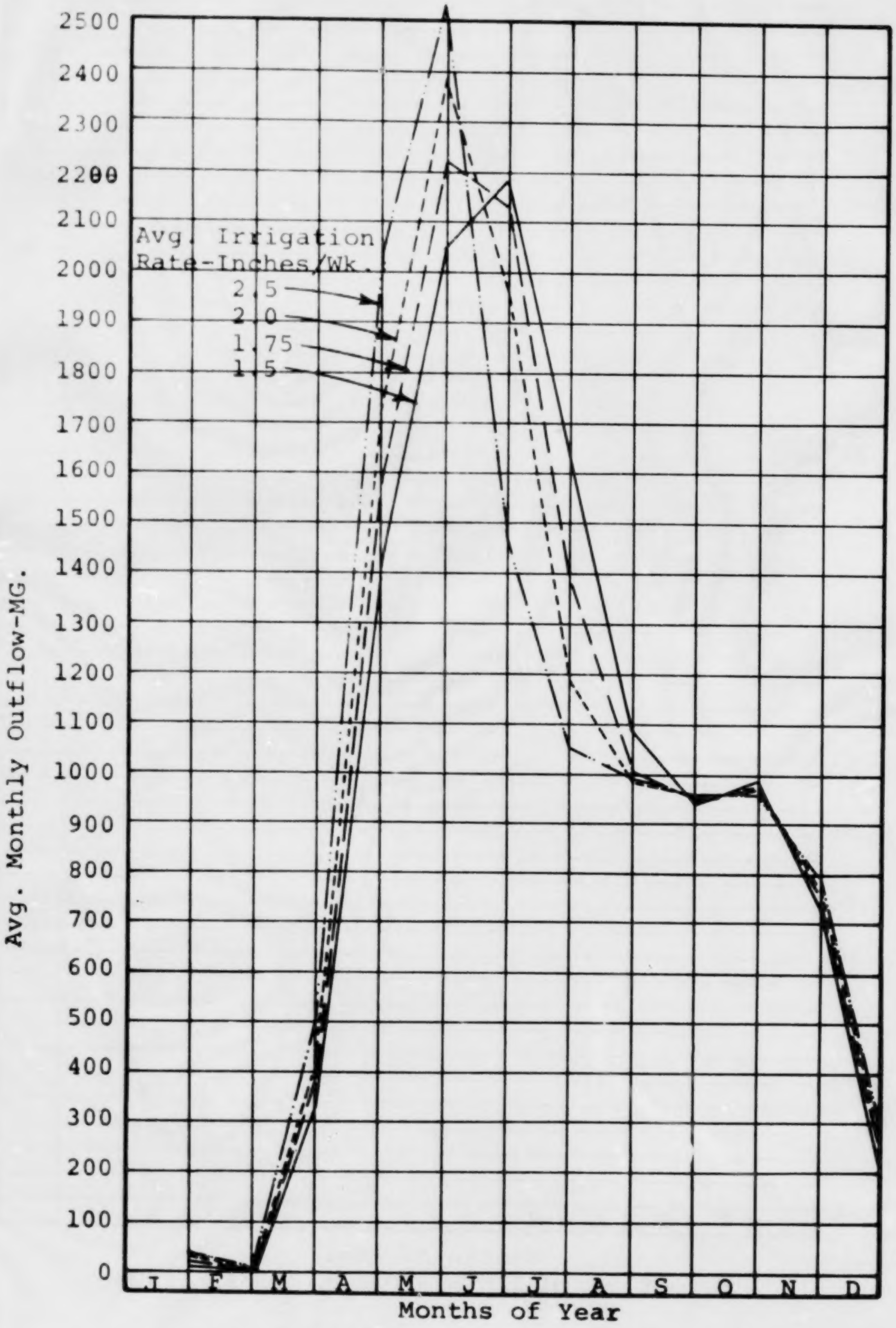


FIGURE 6: AVERAGE MONTHLY OUTFLOW

Simulation Program Listing and Documentation

The simulation program is written in FORTRAN IV for acceptance by the ge mark I series computer. With minor conversion it can be accepted by other FORTRAN IV systems (IBM, CDC, Honeywell, etc.) as well. Running time for 22 years of operation is approximately 10 minutes. A teletype time-sharing system was used, and input - output (with the exception of climatological data which were stored on magnetic tape to be called into service via teletype) was by teletype.

The program listing is reproduced as Table 21 and is followed by Table 22 which identifies the variables used in the program.

TABLE 21: SIMULATION PROGRAM LISTING

```
100$RPC
105      DIMENSIØN THITA(3),K20(3),KT(4)
110 CØMMØN HAL(10),AREA(10),HIR(10),AVT(31)
120 CØMMØN TLAGT(31),ST(31),BD(31),DØØ3(31),TS(31)
130 CØMMØN ND(12),SETUP(50),SUM(4,12,9)
140 CØMMØN BØDØ9(31),Q(31),XMIN,XMAX,AVG,SDEV,NXX
150 CØMMØN TØUTF,I,NYRS,NYRA,NYRB,DØWN(12),TFLØW(12)
160 CØMMØN IØUTF(12),XMST(12),NYR,MAXYR(12),NAB
170 CØMMØN XNYRS,MAR(12),MZYR(12)
180      REAL IØUTF,LSET,LB,K20,KT
190 CALL ØPENF(1,"YEAR10")
200 CALL ØPENF(4,"YEAR20")
210 CALL ØPENF(3,"YEAR05")
220 PRINT,"ENTER IN QUØTES NAME ØF ØUTPUT FILE"
230      INPUT,IØUTF
240      PRINT 2
250  2  FØRMAT("ENTER VALUES FØR PRINT ØPT, BEGIN YEAR, END YEAR,"/
260&" AND INITIAL VALUES FØR STØRAGE,DØP,BØDP,TLAGP")
270      INPUT, IØPT,NYRA,NYRB,STØR,DØP,BØDP,TLAGP
272      PRINT,"MAX. WØRKING STØRAGE IN M.G."
275      XRRRAT=2.0
280      WRITE(2;4)
282      WRITE(2;339)
283      WRITE(2;440)
285      WRITE(2;441) XRRRAT
290  4  FØRMAT("NØTE: AVG.REPRESENTS AVG. ØVER NØ. ØF YEARS STUDIED")
292 339 FØRMAT("LAGØØN STØRAGE LISTED IS WØRKING VØLUME")
293 440 FØRMAT("TØTAL LAGØØN STØRAGE=WØRKING VØL. +1100 M.G.")
295 441  FØRMAT("       MAX. WEEKLY IRRIGATIØN RATE=",F4.1," IN."/)
300      WRITE(2;666)
310      NYRS=NYRB+1-NYRA
320      XNYRS=NYRS
330      E=2.718281828
340      TLAGP=(TLAGP-32.)*5./9.
350      QI=32.
360      DØI=2.
370      BØDI=125.
380      SSI=500.
385      TSS=0.
390      ND(1)=31
400      ND(2)=28
410      ND(3)=31
420      ND(4)=30
430      ND(5)=31
440      ND(6)=30
450      ND(7)=31
```

TABLE 21 (continued)

```
460      ND(8)=31
470      ND(9)=30
480      ND(10)=31
490      ND(11)=30
500      ND(12)=31
510      NAR=2
520 HAL(1)=2.62/7.0
530  HAL(2)=2.62/7.0
540      AREA(1)=4470.
550      AREA(2)=5000.
560      ALAG=1150.
580      C1=29.
590      C2=44.
600      XK1=1.21
610      XK2=0.97
620      TB=32.
630      XØ=0.
640      TAVEP=32.
650      XLH=4000.
671      P=4.0
675      THITA(1)=1.047
677      THITA(2)=1.027
678      THITA(3)=1.047
680      K20(1)=0.18
690      K20(2)=0.2
691      K20(3)=0.
692      KT(4)=.007
700      FAER=0.000012
710      FLAG=0.11
715      AAER=36*43560
720      DØ 1515 I=1,12
730      DØWN(I)=0.
740      XMST(I)=0.
750      MAR(I)=0
760 1515 TFLØW(I)=0.
770      DØ 15 L=1,4
780      DØ 15 I=1,12
790      DØ 15 K=1,9
800 15   SUM(L,I,K)=0.
810 990 NYR=NYRB+1-NYRS
820      IF(NYR.EQ.48.ØR.NYR.EQ.52.ØR.NYR.EQ.56.ØR.NYR.EQ.60.ØR.
830&NYR.EQ.64.ØR.NYR.EQ.68) GØ TØ 333
840      ND(2)=28
850      GØ TØ 3
860 333 ND(2)=29
870  3   CØNTINUE
880      IF(NYRS)72,72,48
890 48   DØ 70 I=1,12
900 666 FØRMAT(//)
910      IF(LØPT.EQ.1) GØ TØ 36
```

NOT REPRODUCIBLE

TABLE 21 (continued)

```
920        WRITE(2:411)
930  411 FORMAT(63HDAY        OTFL     STOR  D.J.   BOD  BODW   TSS
940&TLAG  TAVE  HFRZ)
950  36   TOUTF=0.
970        NAB=0
980        NXX=ND(I)
981        GO TO (90,90,90,91,91,91,92,92,92,93,93,93) I
982   90 TIN=12.
983        GO TO 94
984   91 TIN=16.
985        GO TO 94
986   92 TIN=21.
987        GO TO 94
988   93 TIN=17.
989   94 CONTINUE
990        DO 60 J=1,NXX
1000   56 CONTINUE
1010       IF(NYR.LE.55) GO TO 101
1020       GO TO 102
1030 101  READ(1,400) IYR,MONTH,IDAY,TEMP1,TEMP2,PREC,HSC
1040       GO TO 995
1050 102  IF(NYR.GT.55.AND.NYR.LE.63) GO TO 103
1060       READ(3,400) IYR,MONTH,IDAY,TEMP1,TEMP2,PREC,HSC
1070       GO TO 995
1080 103  READ(4,400) IYR,MONTH,IDAY,TEMP1,TEMP2,PREC,HSC
1090 995  TAVE=(TEMP1+TEMP2)/2.
1100 400  FORMAT(5X,3I2,2F3.0,F4.0,3X,F3.0,5X)
1110       HVAL=HVAL-TAVE+32.
1120       IF(TAVE.GT.32.) GO TO 41
1130       TEMP=X0*X0+48.*XK1*(TB-TAVE)/XLH
1140       HFRZ=SQRT(TEMP)
1150       GO TO 601
1160 41   IF(X0.LE.0.) GO TO 51
1170       TEMP=48.*XK2*(TAVE-32.)/XLH
1180       HFRZ=X0-SQRT(TEMP)
1190       IF(HFRZ.LT.0.) HFRZ=0.
1200       GO TO 601
1210 51   HFRZ=0.
1220 601  GO TO (61,61,62,62,63,63,64,64,65,65,66,66) I
1230 61   F=0.101
1240       GO TO 701
1250 62   F=0.200
1260       GO TO 701
1270 63   F=0.298
1280       GO TO 701
1290 64   F=0.294
1300       GO TO 701
1310 65   F=0.194
```

TABLE 21 (continued)

```
1320      GØ TØ 701
1330 66   F=0.124
1340 701  EVA=0.013*F*(TAVE-32.)
1350      IF(EVA.LT.0.) EVA=0.
1360      XØ=HFRZ
1370      TAVEP=TAVE
1380      IF(I.GE.12) GØ TØ 80
1390      IF(I.LT.4) GØ TØ 80
1400      IF(I.GT.4) GØ TØ 81
1410      IF(J.LE.15) GØ TØ 80
1412  81 HICE=0.
1413      GØ TØ 82
1414  80 HICE=10.
1416  82 CØNTINUE
1420  12 IF(TAVE.LE.32.) GØ TØ 20
1430      IF(HFRZ.GT.0.) GØ TØ 20
1440      QØ=0.
1450      DØ 10 K=1,NAR
1460      HIR(K)=HAL(K)+EVA-PREC
1470  10 QØ=QØ+HIR(K)*AREA(K)/(1.547*24.)
1480      IF(QØ.LT.0.) QØ=0.
1490      GØ TØ 30
1500  20 QØ=0.
1506  30 TAVEC=(TAVE-32.)*5./9.
1508      TAER=(FAER*AAER*TAVEC+QI*TIN)/(FAER*AAER+QI)
1510      TLAGC=(STØR*TLAGP+QI*TAER+FLAG*ALAG*(TAVEC-TLAGP))/(STØR+QI)
1515      IF(TLAGC.LT.4.) TLAGC=4.
1520      TLAG=TLAGC
1530      DØ 110 IB=1,3
1540      KT(IB)=K20(IB)*(THITA(IB)**(TLAGC-20.))
1550 110 CØNTINUE
1555      X=5.*KT(1)
1560      SDØ=(475.-0.50)/(33.5+TLAGC)
1565      BØDSØL=(0.48-0.012*TAER)*BØDI
1568      LSET=(BØDI-BØDSØL)/(1.-1./(E**X))
1570      DØT=(DØP*STØR+DØI*QI)/(STØR+QI)
1580      BØD=(BØDP*STØR+BØDSØL*QI)/(STØR+QI)
1590  IF(QØ.GT.STØR+QI-1100.)  QØ=STØR+QI-1100.
1600      STØR=STØR+QI-QØ
1610      X=5.*KT(1)
1620      BØDULT=BØD/(1.-1./E**X)
1650      T=1.
1670      BDR=KT(4)*LSET*(1.-1./(E**(3.*KT(4))))/((E**KT(4))-1.)
1678      EKTT=(KT(1)+KT(3))*T
1679      XKTT=KT(2)*T
1680      DEF=KT(1)/(KT(2)-KT(1)-KT(3))*(BØDULT-BDR/(KT(1)+KT(3)))
1682& *(1./(E**EKTT)-1./(E**XKTT))+(KT(1)/KT(2))
1685& *(BDR/(KT(1)+KT(3))-P/KT(1))*(1.-1./(E**XKTT))+(SDØ-DØT)
1690& *(1./(E**XKTT))
```

TABLE 21 (continued)

```
1698   IF(DEF.LT.0.) DEF=0.
1710      DØØ=SDØ-DEF
1720  IF(HICE.LE.0.)  GØ TØ  50
1740      BØDØ=BØD
1750      GØ TØ 52
1770  50 LB=(BØDULT-BDR/(KT(1)+KT(3)))*(1./(E**(KT(1)+KT(3))))
1775& +BDR/(KT(1)+KT(3))
1790      BØDØ=LB*(1.-1./(E**X))
1795  52 CØNTINUE
1800      IF(DØØ.LT.0.)  DØØ=0.
1810      TSS=8.34*SSI*QI+TSS
1820      TØUTF=TØUTF+QØ
1830      BØDW=BØDØ*8.34*STØR/2000.
1840      BØDØØ(J)=BØDØ
1850      IF(DØØ.EQ.0..AND.HICE.LE.0..AND.STØR.NE.0.) NAB=NAB+1
1860      TS(J)=TSS/2000000.
1880      DØØØ(J)=DØØ
1890      ST(J)=STØR-1100.
1900      BD(J)=BØD
1910      TLAGT(J)=TLAG
1920      Q(J)=QØ
1940      AVT(J)=TAVE
1950      IF(IOPT.EQ.1)GØ TØ 37
1960      WRITE(2;140)J,QØ,STØR,DØØ,BØDØ,BODW,TS(J),TLAG,TAVE,HFRZ
1965 IF(I.EQ.12) PRINT 140,J,QØ,STØR,DØØ,BØDØ,BØDW,TS(J),TLAG,TVE,HFRZ
1970 37  DØP=DØØ
1980     BØDP=BØDØ
1990 60 TLAGP=TLAG
2000     IF(IOPT.EQ.1) GØ TØ 69
2010     WRITE(2;666)
2020 140 FØRMAT(I3,4X,F6.1,F8.1,2F6.2,5F6.1)
2030     GØ TØ 70
2040 69  CALL MØNTH
2050 70 CØNTINUE
2060     NYRS=NYRS-1
2070     GØ TØ 990
2080 72  CALL CENTUR
2090 CALL CLØSEF(2,IØUTF)
2100     PRINT 134
2110 134 FØRMAT("FØR RESULTS PLEASE LIST ØUTPUT FILE")
2120     STØP
2130     END
2140 SUBRØUTINE STAT
2150     NN=NXX
2160     DØ 99 II=1,NN
2170     JLØ=II+1
2180     DØ 99 J=JLØ,NN
2190     IF(SETUP(II).LT.SETUP(J)) GØ TØ 99
2200 11  TEMP=SETUP(II)
```

TABLE 21 (continued)

```
2210      SETUP(II)=SETUP(J)
2220      SETUP(J)=TEMP
2230 99   CØNTINUE
2240      XMIN=SETUP(1)
2250      XMAX=SETUP(NN)
2260      XSUM=0.
2270      SUMSQ=0.
2280      DØ 96 II=1,NN
2290      XSUM=XSUM+SETUP(II)
2300 96   SUMSQ=SUMSQ+SETUP(II)*SETUP(II)
2310      XN=NN
2320      AVG=XSUM/XN
2330      SDEV=(XN*SUMSQ-(XSUM*XSUM))/(XN*(XN-1.0))
2340      SDEV=SQRT(SDEV)
2350      RETURN
2360      END
2370 SUBRØUTINE MØNTH
2380 DIMENSIØN A(40)
2390      DØ 3 J=1,NXX
2400  3   SETUP(J)=Q(J)
2410      CALL STAT
2420      A(1)=XMIN
2430      A(8)=XMAX
2440      A(15)=AVG
2450      A(22)=SDEV
2460      DØ 4 J=1,NXX
2470  4   SETUP(J)=ST(J)
2480      CALL STAT
2490      A(2)=XMIN
2500      A(9)=XMAX
2504      PRINT 71,XMAX
2506 71 FØRMAT(1X,F6.1)
2510      IF(A(9).LE.XMST(I)) GØ TØ 59
2520      XMST(I)=A(9)
2530      MAXYR(I)=NYR
2540  59 CØNTINUE
2550      IF(NAB.LE.MAR(I)) GØ TØ 62
2560      MAR(I)=NAB
2570      MZYR(I)=NYR
2580 62   A(16)=AVG
2590      A(23)=SDEV
2600      DØ 5 J=1,NXX
2610  5   SETUP(J)=D000(J)
2620      CALL STAT
2630      A(3)=XMIN
2640      A(10)=XMAX
2650      A(17)=AVG
2660      A(24)=SDEV
```

TABLE 21 (continued)

```
2670      DO 6 J=1,NXX
2680  6   SETUP(J)=BODOD(J)
2690      CALL STAT
2700      A(4)=XMIN
2710      A(11)=XMAX
2720      A(18)=AVG
2730      A(25)=SDEV
2810      DO 8 J=1,NXX
2820  8   SETUP(J)=TS(J)
2830      CALL STAT
2840      A(5)=XMIN
2850      A(12)=XMAX
2860      A(19)=AVG
2870      A(26)=SDEV
2880      DO 9 J=1,NXX
2890  9   SETUP(J)=TLAGT(J)
2900      CALL STAT
2910      A(6)=XMIN
2920      A(13)=XMAX
2930      A(20)=AVG
2940      A(27)=SDEV
2950      DO 10 J=1,NXX
2960  10  SETUP(J)=AVT(J)
2970      CALL STAT
2980      A(7)=XMIN
2990      A(14)=XMAX
3000      A(21)=AVG
3010      A(28)=SDEV
3090      MUM=0
3100      DO 20 L=1,4
3110      DO 20 K=1,7
3120      MUM=MUM+1
3130 20   SUM(L,I,K)=SUM(L,I,K)+A(MUM)/XNYRS
3140      KZ=0
3150      DO 77 J=1,NXX
3160      IF(Q(J).EQ.0) KZ=KZ+1
3170  77 CONTINUE
3180      XKZ=KZ
3190      DOWN(I)=DOWN(I)+XKZ/XNYRS
3200      TFLOW(I)=TFLOW(I)+TOUTF/XNYRS
3210      RETURN
3220      END
3230 SUBROUTINE CENTUR
3240      DO 90 I=1,12
3250      WRITE(2,100)NYRA+1900,NYRB+1900,I,ND(I)
3260 100 FORMAT(7H YEARS:,I4,4H TO ,I4,8X,7H MONTH:,I3,8X,22H
3270&NO. OF DAYS IN MONTH:,I3//)
```

TABLE 21 (continued)

```
3280      WRITE(2;61)
3262 61 FØRMAT(65H          LAGØØN   LAGØØN   LAGØØN   LAGØØN    TØTAL
3285&   LAGØØN    AIR,/,67H        ØUTFLØW  STØRAGE   D.Ø.     B.Ø.D.
3286&  SUS.SØL.  TEMP.     TEMP. ,/,65HAVG.   M.G.D.    M.G.
3288&MG./L.   MG./L.    1000T.      C.          F.,/)
3310      WRITE(2;62) (SUM(1,I,K),K=1,7)
3320      WRITE(2;63) (SUM(2,I,K),K=1,7)
3330      WRITE(2;64) (SUM(3,I,K),K=1,7)
3340      WRITE(2;65) (SUM(4,I,K),K=1,7)
3350 62  FØRMAT("MIN. ",F7.1,F10.1,F8.2,F9.2,3F9.1)
3360 63  FØRMAT("MAX. ",F7.1,F10.1,F8.2,F9.2,3F9.1)
3370 64  FØRMAT("MEAN ",F7.1,F10.1,F8.2,F9.2,3F9.1)
3380 65  FØRMAT("STDEV",F7.1,F10.1,F8.2,F9.2,3F9.1)
3390 777 FØRMAT(///)
3400      WRITE(2;5) DØWN(I)
3410  5  FØRMAT(/,"AVG. NUMBER ØF DAYS WITHØUT IRRIGATIØN FØR MØNTH="
3415&,I3/)
3420      WRITE(2;55) XMST(I),MAXYR(I)+1900
3430 55  FØRMAT("MAX. STØRAGE FØR MØNTH="F8.1," M.G."/
3440&"ØCCURRED IN YEAR:"I5/)
3450      WRITE(2;6) TFLØW(I)
3460  6  FØRMAT("AVG. TØTAL MØNTHLY IRRIGATIØN (ØUTFLØW)="F8.1," M.G."/)
3470      IF(MAR(I).EQ.0) GØ TØ 76
3480      WRITE(2;66) MAR(I),MZYR(I)+1900
3490 66 FØRMAT("MAX. DAYS ANAERØBIC CØNDITIØNS WITH NØ ICE CØVER=",I3/
3500&"ØCCURRED IN YEAR:",I5)
3510      GØ TØ 751
3520 76  WRITE(2;757)
3530 757 FØRMAT("MAX. DAYS ANAERØBIC CØNDITIØNS WITH NØ ICE CØVER= 0.")
3558 751 WRITE(2;777)
3559  90 CØNTINUE
3560 RETURN
3570 END
```

TABLE 22: SIMULATION PROGRAM VARIABLE NAME IDENTIFICATION

Variable Name	Description	Units
A	Array used to store monthly output summary	
AAER	Area of aerated lagoon	sq. ft.
ALAG	Area of storage lagoon	acres
AREA	Area of irrigation	acres
AVG	Contains the means of a given variable after ordering	
AVT	Average daily temperature	°F
BD	Biochemical Oxygen demand in storage lagoons	mg/l
BDR	Benthal demand rate	mg/l/day
BODI	BOD inflow from aerated lagoon	mg/l
BODO	BOD outflow	mg/l
BODOO	BOD outflow	mg/l
BODP	BOD initial for storage lagoon	mg/l
BODSOL	Nonsetteable BOD	mg/l
BODULT	BOD ultimate	mg/l
BODW	BOD weight	#
DEF	DO deficit	mg/l
DOI	Inflow dissolved oxygen	mg/l
DOO	DO outflow	mg/l
DOOO	DO outflow	mg/l
DOP	Initial DO	mg/l
DOT	Dissolved oxygen after mixing	mg/l
DOWN	No. days in month w/o irrigation	days
E	Natural logrithmic base 'e'	
EKTT	Factor in BOD-DO equations	
EVA	Evaporation	inches
F	Seasonal evaporation constant	
FAER	Self-purification factor aerated lagoons	
FLAG	Self-purification factor storage lagoons	
HAL	Amount of irrigation specified	inches
HFRZ	Height of freezing soil zone	inches
HICE	Height of ice on lagoon	inches
HIR	Actual amount of irrigation	inches
HSC	Height of snow cover	inches
HVAL	Heat value	°F
IDAY	Day of month from input data file	

TABLE 22 (continued)

Variable Name	Description	Units
IOPT	Flag to indicate output option, O=daily I=monthly summary	
IOUTF	Name of teletype input file	
IYR	Year from input data file	
K20	Reaction rates at 20°C	
KT	Reaction rates at 'T'-°F	
KZ	No. of days in given month w/o irrigation	
LB	BOD after 1-day in lagoon	mg/l
LSET	Settleable BOD	mg/l
MAR	Maximum no. days anaerobic conditions in any given month	days
MAXYR	Contains the year in which max. monthly storage, XMST occurs	year
MXYR	Year in which max. monthly anaerobic conditions occur	year
MONTH	Month from input data file	
NAB	Contains the number of days in month with critical anaerobic conditions	days
NAR	No. of subareas at irrigation site	
ND	Number of days in month	
NXX	No. of days in a given month	days
NYR	Year currently being simulated	
NYRA	Beginning year of simulation	
NYRB	End year of simulation	
NYRS	No. of years in simulation	no. years
P	Photosynthesis oxygenation rate	mg/l/day
PREC	Precipitation	inches
Q	Flow out	M.G.
QI	Flow in	MGD
QO	Flow out	MGD
SDEV	Contains the standard deviation of a given variable after ordering	
SDO	Saturated DO	mg/l
SETUP	Used for statistical analysis	
SSI	Suspended solids inflow	mg/l
ST	Stored volume in storage lagoons	M.G.
STOR	Storage	MG
SUM	Three dimensional accumulation array	
SUMSQ	Used to compute standard deviation	
T	Time in days	
TAER	Average temperature of storage lagoon	°C

TABLE 22 (continued)

Variable Name	Description	Units
TAVEC	Average daily temperature	°C
TAVEP	Previous day average lagoon temperature	°F
TB	Temperature at bottom layer of frozen soil cover	°F
TEMP	Temporary computer storage location	
TEMP_1	Min. daily temperature from input data file	°F
TEMP_2	Max. daily temperature from input data file	°F
TFLOW	Aug. Total irrigation outflow for given month	MG
THITA	Theta (θ)	
TIN	Temperature inflow	°F
TLAG	Temperature lagoon	°F
TLAGC	Temperature lagoon	°C
TLAGP	Temperature initial	°C
TLAGT	Temperature lagoon	°F
TOUTF	Total irrigation outflow for a given month	MG
TS	Total suspended solids	
TSS	Total suspended solids	
X	Factor in BOD-DO equations	
XK1	Temperature proportionality factor for aerated lagoon	
XK2	Temperature proportionality factor for storage lagoons	
XKTT	Factor in BOD-DO equations	
KLH	Specific heat conductivity	
XMAX	Contains max. monthly value of a given variable after ordering	
XMIN	Contains min. monthly value of a given variable after ordering	
XMST	Contains maximum monthly storage for any given month at any given time of simulation	MG
XNYRS	No. year of simulation in floating point format	years
XO	Initial depth of frozen soil	ft.
XRRAT	Wastewater irrigation rate	in./week
XSUM	Used to compute mean and standard deviation	
YEAR 10	Input file name	
YEAR 20	Input file name	
YEAR 05	Input file name	

SECTION VIII

SOILS AND GROUNDWATER INVESTIGATIONS

Introduction

The purpose of the soils and groundwater investigations was to demonstrate the feasibility of managing the groundwater levels in the irrigation site areas. Included in these studies were nine test hole boring and two aquifer test wells by the Layne-Northern Company, Inc. at the locations shown on Figure 7. Also shown on Figure 7 is the initial irrigation site study area. The basic analyses and interpretations of the test well data were done by Dr. W. E. Keck of W. E. Keck & Associates, Inc., while the overall analyses and interpretations of the soils and test well data were under the direction of Dr. James E. Hackett.

The information developed confirmed the feasibility of groundwater level management within the study area by using drainage wells or drainage tile, depending upon the available aquifer thickness. In areas where wells are feasible, spacing is estimated to range from about 800 feet to about 4,500 feet with approximately 50 to 2 wells required per square mile. The larger spacing and resultant fewer number of wells per square mile would prevail in areas having greater aquifer thickness.

In areas having insufficient aquifer thickness for drainage wells, drainage tiles could provide groundwater level control, with spacings ranging from about 200 feet to 1,500 feet. As in the case of drainage wells, the larger drainage tile spacings would prevail in areas with thicker aquifers.

Another result of this study has been the determination of the approximate maximum time needed to dewater portions of the irrigation site area prior to operation of the system. In sections where the ground is now completely saturated, about 400 days would be required for dewatering. This time would be less where the present zone of saturation is less.

Testing and Analysis Program

Test borings for formational data were drilled with a 2-1/2 inch split spoon sampler. Split spoon samples were taken at five foot intervals. Mechanical analysis of selected samples were made for all of the test borings. Gamma ray logs

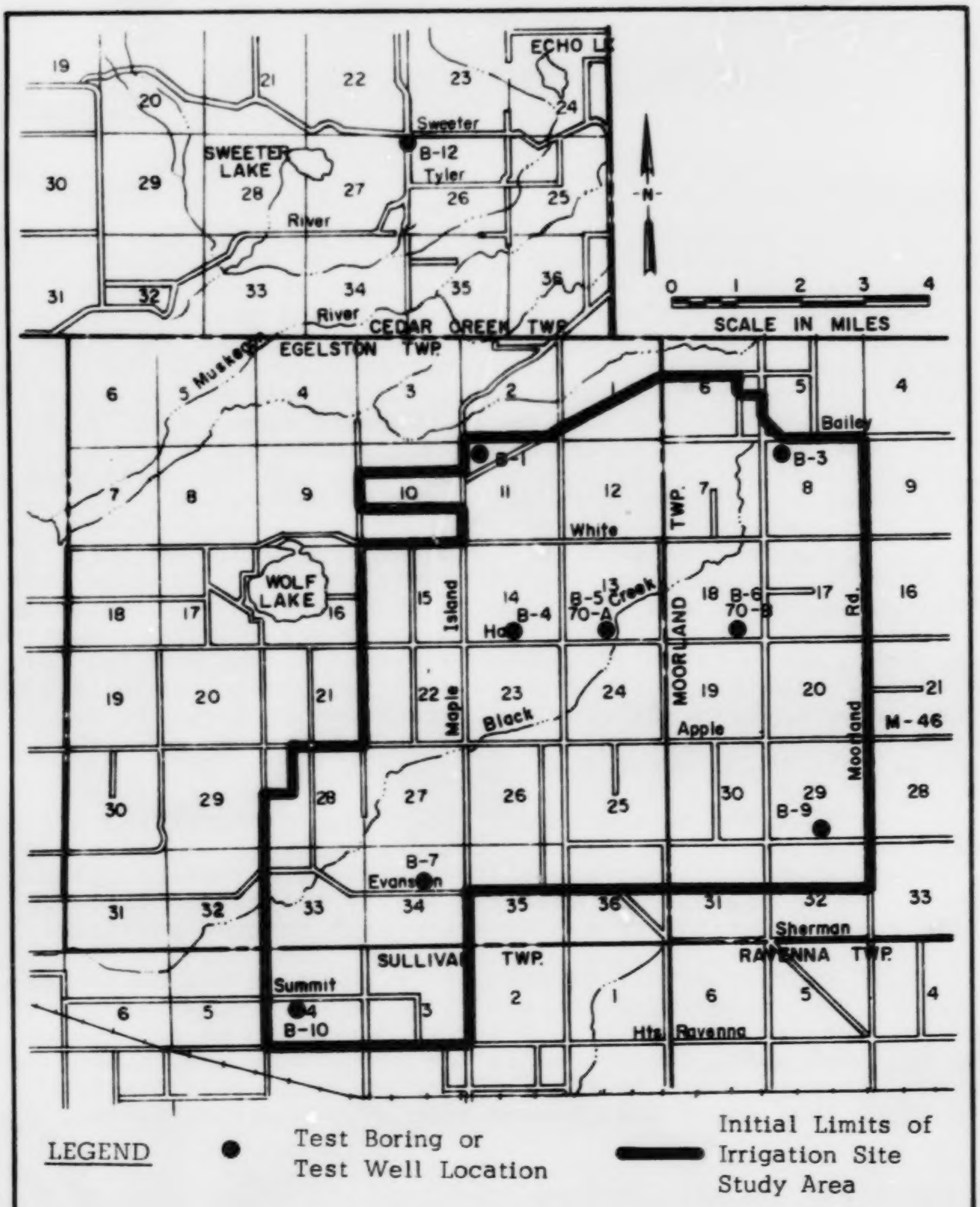

ECHO LK
SWEETER LAKE
Sweeter
B-12
Tyler
River
CEDAR CREEK TWP.
EGELSTON TWP.
Muskegon
-N-
0 1 2 3 4
SCALE IN MILES
Bailey
B-1
B-3
White
TWP.
WOLF LAKE
Island
Maple
Ho
B-4
B-5
70-A
Creek
B-6
70-B
Rd.
MOORLAND
Moorland
Black
Apple
M-46
B-9
B-7
Evanston
Sherman
SULLIVAN TWP.
RAVENNA TWP.
Summit
B-10
Hts. Ravenna
LEGEND
Test Boring or Test Well Location
Initial Limits of Irrigation Site Study Area

FIGURE 7: TEST BORINGS AND TEST WELL LOCATIONS

were provided for test borings B-1, B-3, B-7, B-9, and B-10.

Test borings B-1, B-3, B-5, B-7, B-9, and B-10 were drilled in the initial stages of the investigative programs. Based on results of these six initial borings, the locations for test borings B-4, B-6, and B-12 were designated, and a test well (70A) with two observation wells was drilled for a short-term pumping test in the vicinity of test boring B-5.

Test borings B-4 and B-6 were drilled to better establish distributional characteristics of stratigraphic units and to select the site for a second pumping test within the proposed project area. Test well 70B was drilled in the vicinity of test boring B-6 which was used as one of the two observation wells for the pumping test, the second being drilled at the time of construction of the test well. Test boring B-12 was drilled on the uplands north of the Muskegon River outside of the proposed project area to determine subsurface characteristics of that area. The similarity of stratigraphic relations north of the Muskegon River to the proposed project area was demonstrated by this boring and no further investigations in that area were felt to be justified during these studies.

Test wells 70A and 70B were drilled as pump wells for short-term pumping tests to determine transmissibility coefficients of the underlying aquifer. Twenty-four hour tests were considered to be of sufficient duration to establish those hydrologic parameters most significant to meet the study objectives within the time and financing limits set for these investigations.

Both test wells were 8-inch diameter tubular wells drilled to the base of the uppermost clean sand zone and were fitted with 10 feet of gauze screen at the base of the well. Well production data and water level responses in observation wells during the pumping and recovery stages of the test were made and were analyzed to determine coefficients of transmissibility, expectable pumping rates for drainage wells, and projected well spacings at the respective pumping test sites.

Analyses of physical feasibility for the management program based on the geologic and hydrologic data produced by the testing program include: the definition of major stratigraphic units underlying the project area and their spatial relationships; ground-water depth and flow conditions; regional hydrologic patterns of transmissibility, available drawdown, drainage well spacings and drainage tile spacings; and dewatering times for drainage installations. These analyses provide the basis for general conclusions regarding physical feasibility of the project area to provide the necessary drainage control for spray irrigation of waste water, differentiation of management subareas within the project area reflective of variations in applicable drainage control measures, and additional investigative needs to substantiate area characteristics suitable for general system design.

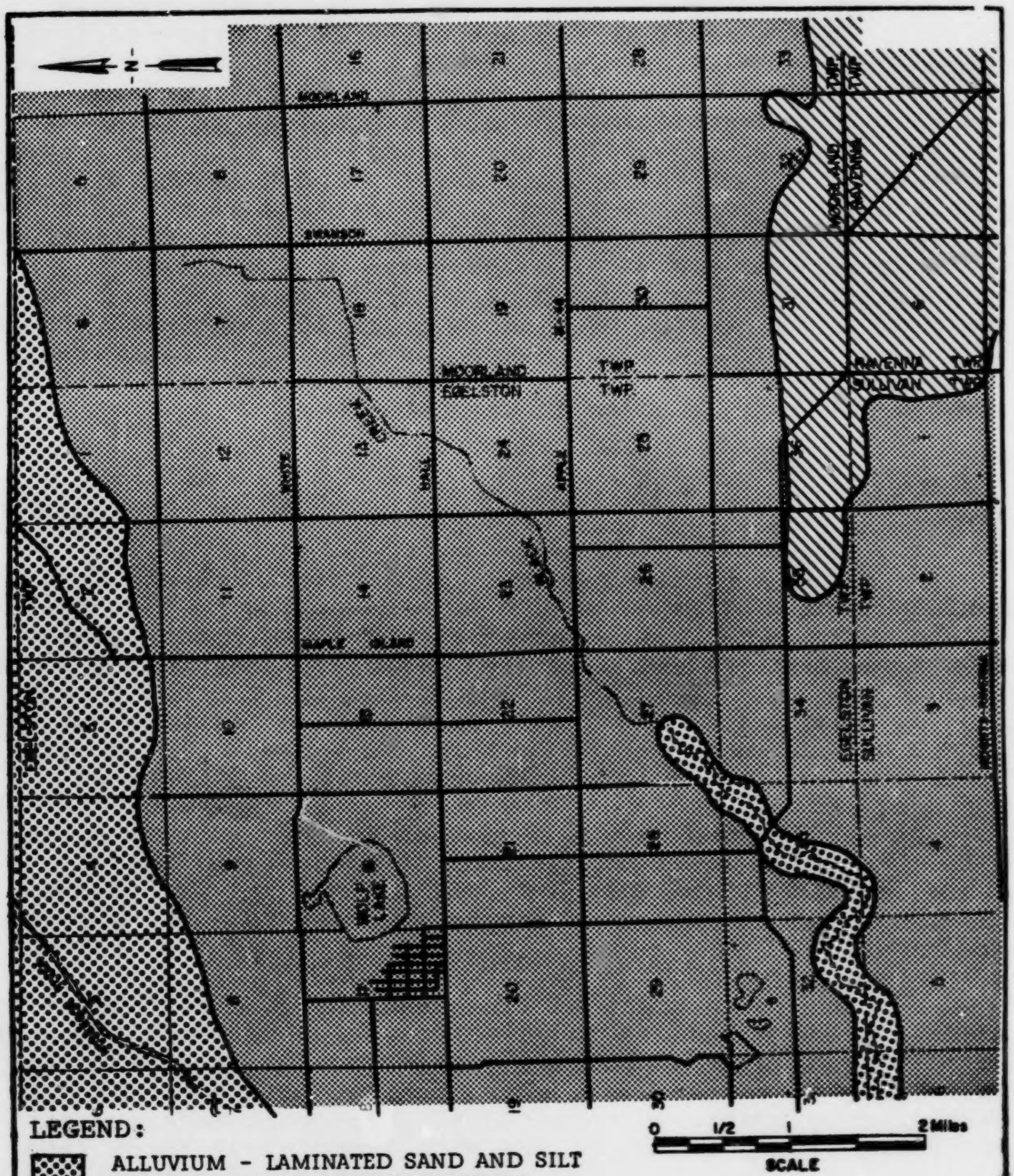
Geologic Setting of Project Area

The project area is underlain by deposits associated with the galcial lake plain, the outwash plain and the Lake Border morainal upland which are major physiographic elements within Muskegon County. Regional description of geologic conditions and relationships within the county are given in "Physical Characteristics of Muskegon County" by J. E. Hackett and T. A. Dumper, a report to the Muskegon County Regional Planning Commission. The deposits of the glacial lake plain and the outwash plain are underlain by sands and minor amounts of gravel so similar in composition and texture that distinctions between the two cannot be made on a materials basis. The Lake Border morainal uplands are underlain by a silty sand clay till with some isolated deposits of sand and gravel. The glacial lake and outwash sand are underlain by silty clay till. The total thickness of these sands are determined by test borings ranging from 17 feet to 130 feet. The surficial distribution of these deposits and associated alluvium within the project area are shown on Figure 8.

Because the area underlain by glacial till is too low in permeability to be suited for wastewater applications, only the lake plain and outwash sands were subjected to detailed study. The physical feasibility for wastewater management by spray irrigation is largely a function of formational and hydrologic characteristics of these sands.

Stratigraphic Relations

Test borings within the project area demonstrate the presence of three major stratigraphic units in the subsurface. These three units have been informally designated as zones A, B and C for purposes of regional analysis. No attempt has been made to establish genetic relationships for the zones although it is believed that zones A and B are related to the glacial lake and outwash deposits and zone C is related to the glacial tills that underlie the morainal uplands. In general terms, zone A, the upper zone, consists of a fine to medium, well sorted sand. Zone B, the intermediate zone, is a sand zone of extremely variable composition, and zone C, the basal zone, is a sandy clay.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SWANSON
MOORLAND TWP
EGELSTON TWP
MOORLAND TWP
RAVENNA TWP
RAVENNA TWP
SULLIVAN TWP
STATE
HALL
APPLE
BLACK CREEK
MAPLE ISLAND
WOLF LAKE
EGELSTON TWP
SULLIVAN TWP
0
1/2
1
2 Miles
SCALE

LEGEND:

▩ ALLUVIUM - LAMINATED SAND AND SILT WITH PEATY AND FIBROUS MATERIAL

▦ LAKE AND OUTWASH PLAIN DEPOSITS - SAND WITH A LITTLE GRAVEL

▨ MORAINAL DEPOSITS - SILTY AND SANDY TILL - SOME SAND AND GRAVEL

FIGURE 8:
SURFICIAL DEPOSITS

The consistent occurrence of the three zones in all borings conducted in the project area is evidence that the three zones persist as correlatable units throughout the project area beyond the boundaries of the morainal upland. The stratigraphic correlations among borings logs in terms of zones A, B and C are shown on Figures 9 and 10. The primary basis for distinctions between zones A and B is the differences in the percent of fines (less than 200 sieve) obtained by sieve analysis of split spoon samples and descriptions of the character of the material observed by the driller. Graphical representations of percent of fines for each sample analyzed are presented on Figures 9 and 10 along with the log of materials encountered in each test boring to demonstrate these relations. More detailed description of each of the three stratigraphic zones is given below.

Zone A

Zone A is the uppermost zone underlying the land surface throughout the project area excepting in the morainal upland. The materials comprising zone A are predominantly a fine to medium grained sand with generally less than 5 percent fines (less than 200 sieve). Occasionally, coarser textured beds or beds containing higher percentage of fines occur within zone A but these appear to be thin and sporadic in occurrence. Materials assignable to zone A were found to present on all borings. The thickness of the zone ranges from less than 20 feet in test boring B-7 to more than 80 feet in test boring B-1. The upper level of the zone of saturation, the water table, occurs within zone A in all borings and as a consequence the saturated thickness of the zone varies from the formational thickness.

The low percent of fines and the good sorting of the sands in zone A results in relatively high permeability. The relatively high permeability, consistency of occurrence and uniformity of texture that characterizes this zone makes it particularly adaptable to regional hydrologic modeling and analysis. The position of the zone immediately below land surface and extending below the upper level of saturation makes it the most critical zone with regard to water management.

Zone B

The sequence of sand deposits underlying zone A are variable in texture, generally contain higher percentages of

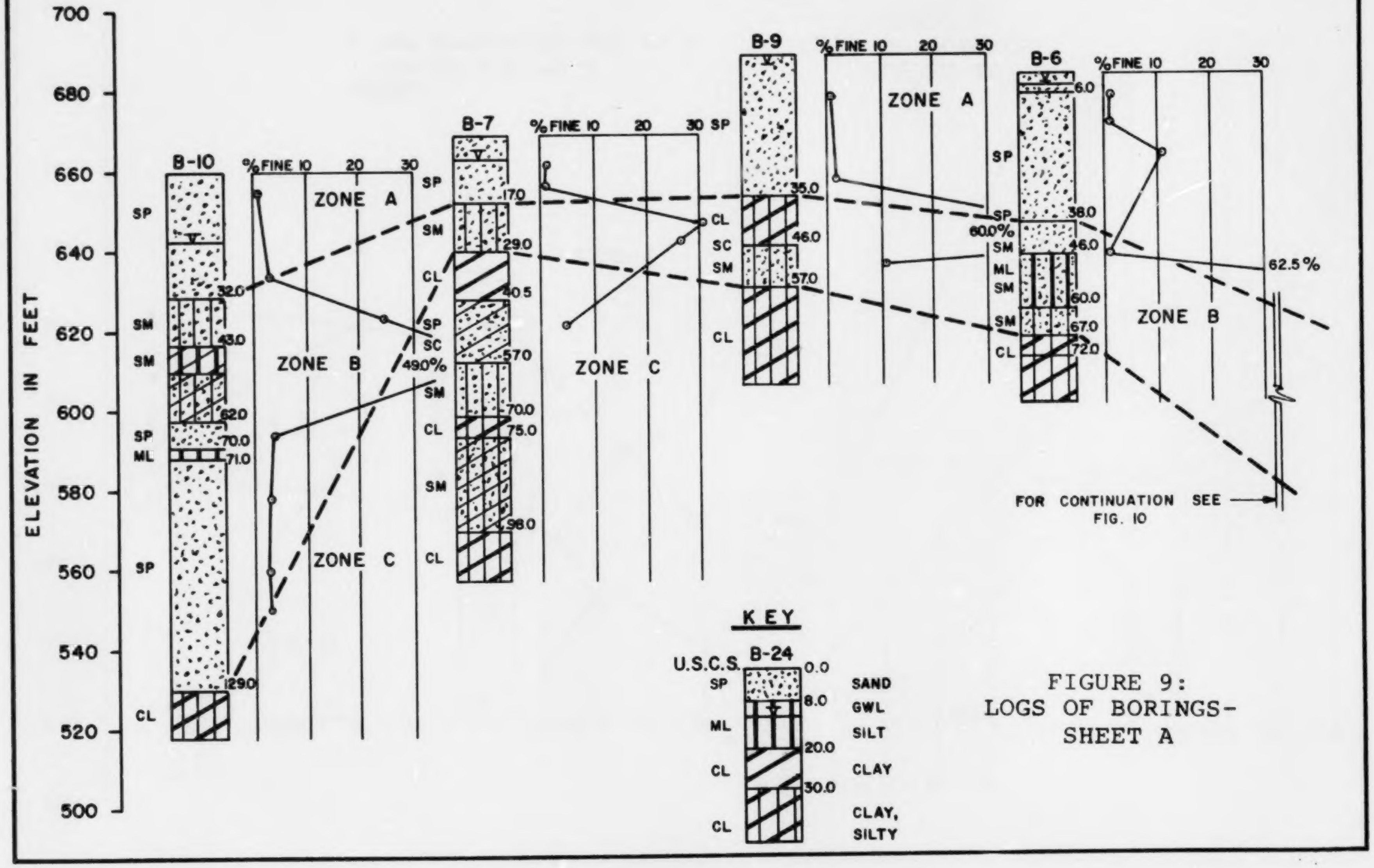
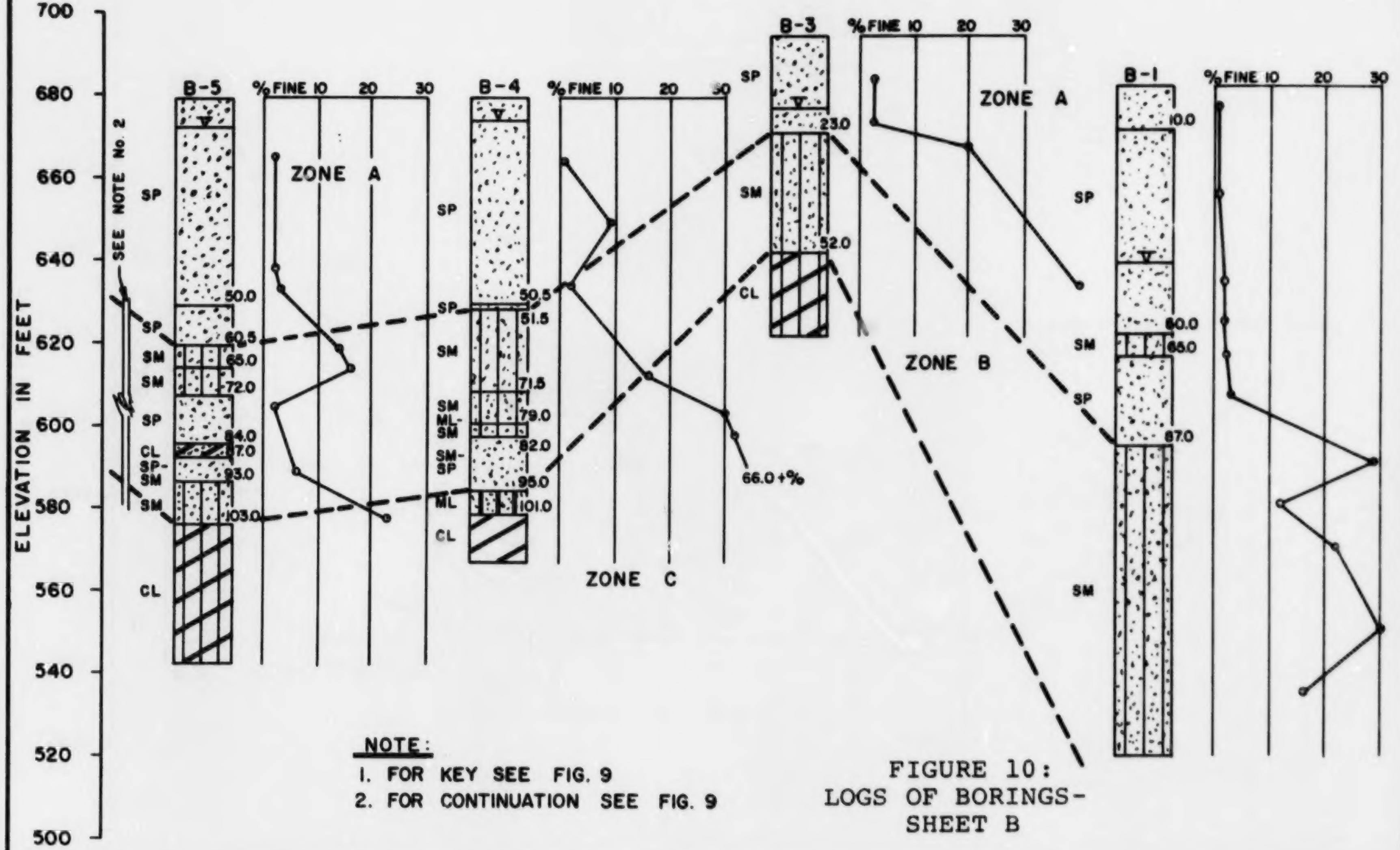


FIGURE 9:
LOGS OF BORINGS-
SHEET A



NOTE:

1. FOR KEY SEE FIG. 9
2. FOR CONTINUATION SEE FIG. 9

FIGURE 10:
LOGS OF BORINGS-
SHEET B

fines (in some units more than 30 percent) and are commonly interbedded with units of silty clay. The general variability and lack of uniformity of these deposits constitute a characteristic zone consistently present between zone A above and the silty clay deposits below. This sequence of materials is designated zone B for correlation purposes. The distribution and textural characteristics of zone B is shown on the correlation profile in Exhibit 3. Although some clean beds of sand similar in character to sands in zone A with less than 10 percent fines occur within zone B, they are generally thin, sporadic in occurrence and are overlain and underlain by materials containing higher percentages of fines. Correlation from boring to boring of individual textural units within zone B was not attempted in the course of this study as it was believed that the zone represented a highly complex pattern of sedimentation and not susceptible to regional correlation.

In all borings except boring B-10, the deposits of zone B were judged to be inadequate in yield potential to permit the development of drainage wells due to the low permeability of the silty andpoorly sorted sands. In test boring B-10, a sufficient thickness of clean and apparently well sorted sand occurs in the basal part of zone B. However, the lack of continuity of these deposits in all other borings within the project area and the presence of beds of lower permeability overlying this permeable interval would delimit the effectiveness of wells in this basal unit to control water table levels at shallow depths below land surface.

As a consequence of the regional characteristics of zone B, it was not considered to be of hydrologic import with regard to management of the groundwater system associated with the wastewater application program. By considering the top of zone B as the effective hydrologic base to the groundwater system management, it is believed that analyses based on the geohydrologic parameters of zone A only would contribute the most usable and conservative results.

Zone C

The distinctive silty clay which comprises zone C is the basal unit of that part of the stratigraphic section of consequence to the management program. The silty clay materials commonly contain 60 percent or greater fines and is of such low permeability that it functions as the base of the groundwater system immediately underlying the project area.

Locally, the silty clay of zone C contain some minor beds of sand and sand with gravel but these are of little consequence to the general characteristics of this zone. The silty clay is believed to be related to the deposits of the morainal uplands as the total thickness of water-laid sands of zones A and B thin adjacent to the morainal area where zone C is encountered at progressively higher levels.

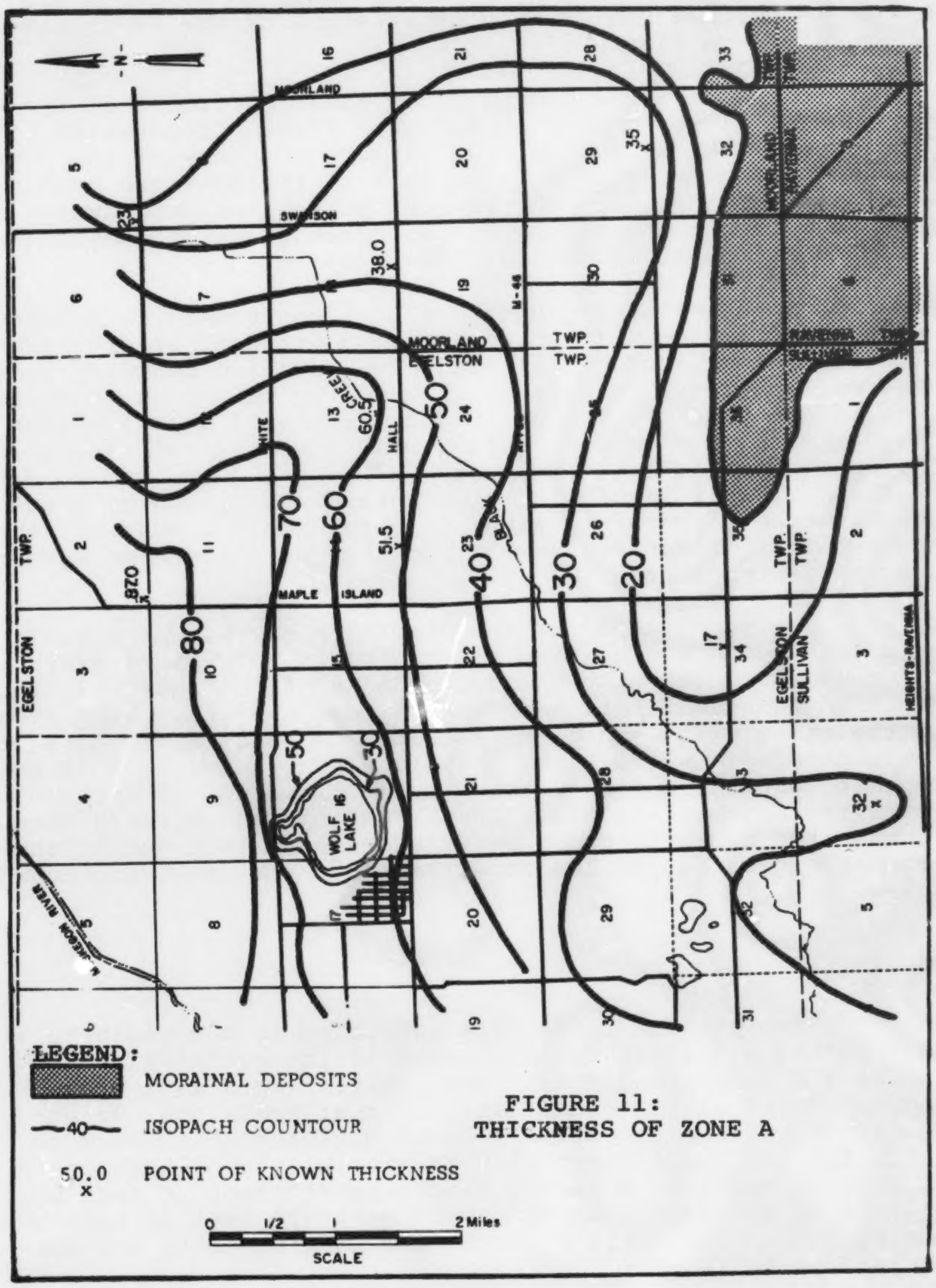
Distributional Characteristics of Zone A

The regional extrapolation of geologic control data and hydrologic characteristics require that stratigraphic units have a predictable pattern of development. The geologic control data obtained in the course of the feasibility study substantiate the premise assumed for the interpretive analysis presented in this report that zone A has a relatively consistent thickness distribution pattern. The general thickness pattern of zone A was indicated by the initial set of six test borings. On the basis of the information obtained in these borings, additional drilling sites were selected at the locations of test borings B-4 and B-6 in anticipation that deposits characteristic of zone A would be present at these locations and that they would thin to the east and be well developed to the west of test boring B-5. These conclusions were subsequently borne out by the data obtained at test borings B-4 and B-6.

On the basis of the data obtained from the test borings, a thickness distribution map of zone A has been constructed and is presented as Figure 11. The map shows a regular and consistent pattern. Zone A thins to the east and south and thickens to the north and west. Zone A assumes the form of a semi-enclosed basin with the axis of the basin oriented to the northwest. Further data will be required to refine the distribution pattern of zone A within the project area, but because the existing control displays no reversals to the pattern trends, it is believed that the general thickness pattern does conform to that presented in Figure 11.

Groundwater Occurrence

The presence of the upper level of the zone of saturation within the highly permeable zone A indicates that water table conditions occur throughout the project area. Conforming to the regional slope of the land surface, water table elevations are highest to the east and south and slope gently to the west. This regional slope of the water table is affected by groundwater discharge to the Muskegon River, Black Creek, and Wolf Lake. The projected elevation of the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32
17
LEGEND:
MORAINAL DEPOSITS
ISOPACH COUNTOUR
POINT OF KNOWN THICKNESS
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1
2 Miles
SCALE

FIGURE 11:
THICKNESS OF ZONE A

water table within the project area, based on static water levels in borings and surface expressions of the water table, is presented on Figure 12.

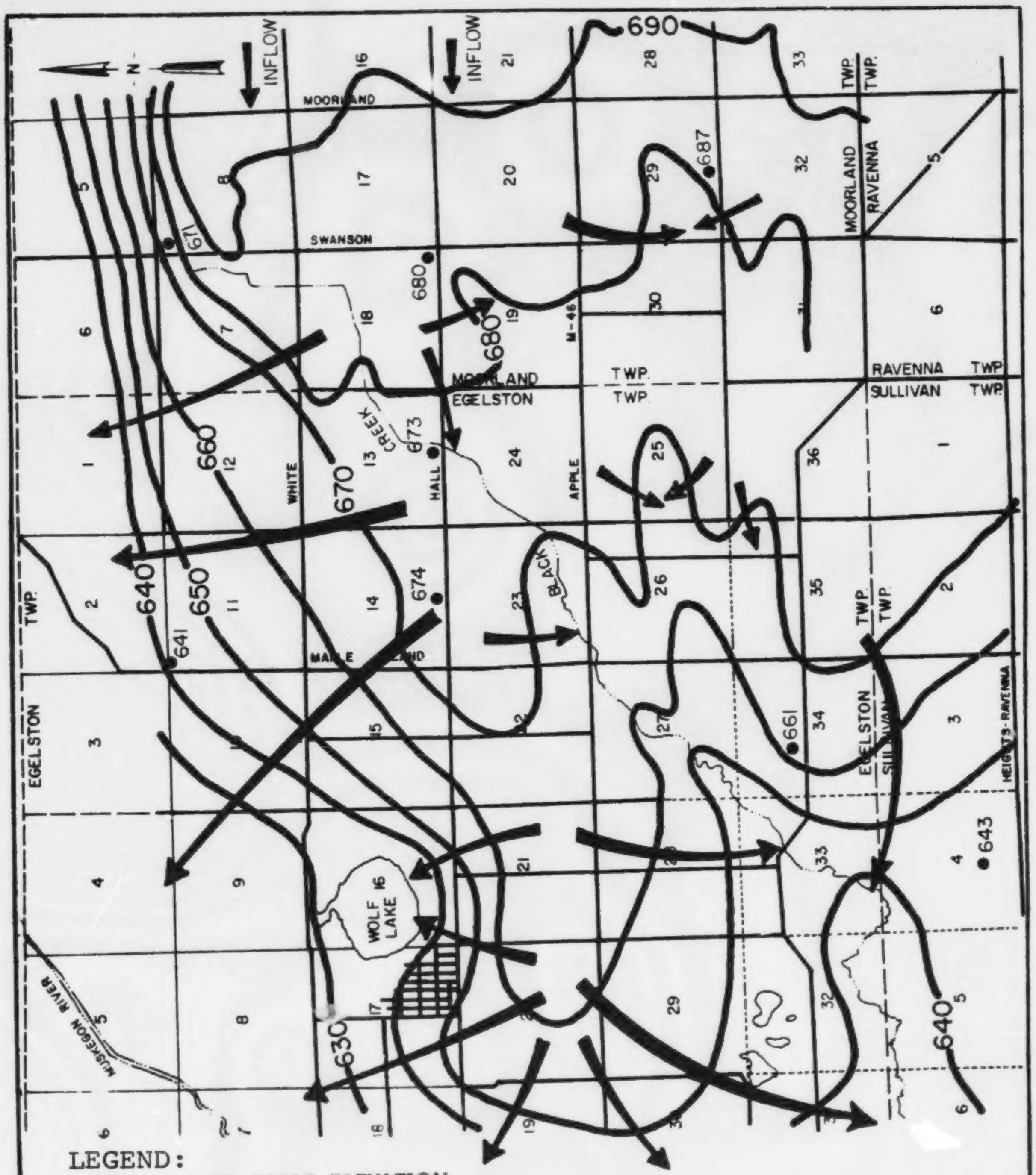
Contour lines on the water table surface indicate the general directions of groundwater flow. Groundwater inflow occurs primarily along the eastern boundary of the project area and secondarily along a portion of the southern boundary. Within the project area the present pattern of groundwater flow is toward the Muskegon River, Black Creek, and Wolf Lake, which functions as a local discharge basin.

With installation of drainage controls such drainage wells and drainage tiles, the existing patterns of groundwater flow will be extensively altered. The eastern boundary of the area will continue to provide groundwater inflow as at present. The western boundary of the project area will also function as an area of groundwater inflow with diversion of flow toward the operational site. The Muskegon River and the lower part of Black Creek will continue to function as discharge areas but with the planned reduction in water table elevation, the upper part of Black Creek will function as a recharge rather than a discharge area.

By subtraction of the elevation of the water table from land surface elevation the regional patterns of depth to groundwater can be projected. As shown on Figure 13, the depth to groundwater is less than 5 feet over extensive areas in the eastern and southern parts of the study area, along the lowlands of Black Creek and immediately adjacent to Wolf Lake. Depth to groundwater increases in the direction of Muskegon River and adjacent to Black Creek. Along the northern boundary of the area depth of groundwater exceeds 25 feet due to the discharge gradient of the water table to the low-lying Muskegon River.

Hydrology

Two aquifer tests were conducted in the vicinity of test boring B-5 (test well 70A) and in the vicinity of test boring B-6 (test well 70B). The aquifer tests were 24-hour pumping tests using 8-inch diameter test wells and two observation wells. The primary purpose of the tests were to establish the coefficient of transmissibility of the zone A aquifer in areas of moderate thickness (63 feet at test boring B-5)and in areas of thinner development (38 feet at test boring B-6). The results of the two pumping tests are summarized as follows: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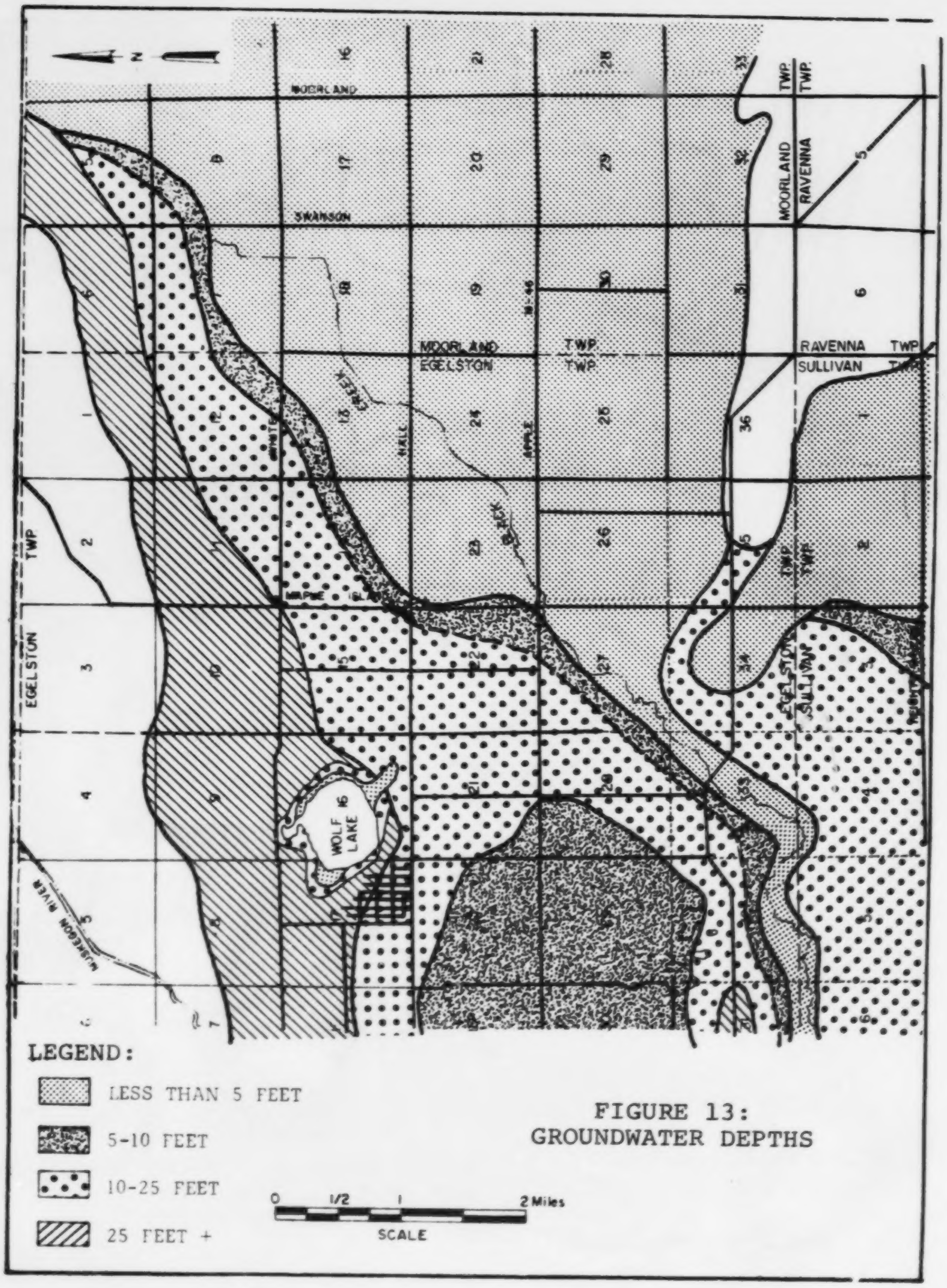
EGELSTON TWP.
SULLIVAN TWP.
HEIGHTS-RAVENNA
WHITE
HALL
APPLE
M-46
MAPLE ISLAND
BLACK CREEK
WOLF LAKE
MUSKEGON RIVER
LEGEND:
● 643 WATER TABLE ELEVATION AT TEST BORING.
GENERAL DIRECTION OF GROUND-WATER FLOW
0 1/2 1 2 Miles
SCALE

FIGURE 12:
WATER TABLE ELEVATION
AND GENERAL DIRECTION
OF GROUNDWATER FLOW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SULLIVAN TWP
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EGELSTON
SULLIVAN
BLACK CREEK
WOLF LAKE
MUSKEGON RIVER
LEGEND:
LESS THAN 5 FEET
5-10 FEET
10-25 FEET
25 FEET +
0 1/2 1 2 Miles
SCALE

FIGURE 13:
GROUNDWATER DEPTHS

Aquifer Test at Test Well 70-A

Pumping rate-100 gallons per minute.
Base of the aquifer at 63 feet. Static water level 1.5 feet.
Saturated aquifer thickness 61.5 feet.
Calculated coefficient of transmissibility (T)-27,200 gallons per day per foot.
Coefficient of transmissibility (T) at operating depth 10 feet below land surface-22,600 gal/day/ft.
Coefficient of permeability (T/aquifer thickness)-443 gallons/day/ft.^{2}
Storage coefficient-0.20.

Drawdown at both observation wells appeared to have reached equilibrium in about 1000 minutes. The value of T obtained in the test should have good reliability. According to Dr. Keck's analysis, wells producing 300 gallons per minute under these aquifer conditions would require a spacing of about 1700 feet to maintain a stabilized water table at 10 feet below land surface at the midpoint between wells. A total recharge (2) of rainfall infiltration plus wastewater application of 0.15 gallons per day per ft.^{2} was assumed.

Aquifer Test at Test Well 70-B

Pumping rate-42.6 gallons/minute.
Base of aquifer 40 feet. Static water level-2.5 feet.
Saturated aquifer thickness 37.5 feet.
Calculated coefficient of transmissibility (T)-14,000 gallons/day/foot.
Coefficient of transmissibility (T) at operating depth 10 feet below land surface-11,200 gal/day/ft.
Coefficient of permeability (T/aquifer thickness)-374 gallons/day/ft.^{2}
Storage coefficient-0.059.

Drawdown at the observation wells did not reach equilibrium by the end of the 24-hour test. The calculated values of (T) required adjustment and the value determined for permeability could be low. Wells producing 95 gallons per minute under these aquifer conditions with an assumed total recharge of 0.15 gallons/day/ft.^{2} would require a spacing of 950 feet to maintain a stabilized water table at 10 feet below land surface at the midpoint between wells.

Dr. Keck's analysis for drawdown relationships are based on Weber's equation. Drawdown relationships under various pumping rates and for various values of T as used in this report are based on the Walton equation in which:

$$s = \frac{114.6\ Q\ R(Z)}{T} \quad \text{and } R(Z) = \frac{r^2 w}{268 \times 10^5 Q} \quad \text{where:}$$

s = Drawdown in feet
Q = Discharge in gpm
T = Transmissibility in gallons/day/foot
r = Distance in feet
w = Recharge in inches/year.

For w (total recharge) Keck applied a value of 0.151 gallons/day/ft.^{2} based on an infiltration of rainfall of 0.018 gallons/day/ft.^{2} and an infiltration of 0.133 gallons/day/ft.^{2} from wastewater application. The latter figure was determined on the basis of an application rate of 1.5 inches per week for 52 weeks with 100% infiltration.

The values of (w) used in this report for regional analysis and drawdown calculations is 0.055 gallons/day/ft.^{2} with 0.018 gallons/day/ft.^{2} assumed as the recharge from rainfall and 0.0370 gallons/day/ft.^{2} due to the application of wastewater. The latter figure is determined on the basis of 1 inch application for 43 weeks with a 50 percent infiltration rate. In terms of inches per year w = A + R = 32 inches/yr. where: A (recharge of applied wastewater) = 21.5 inches per year and R (recharge from rainfall) = 10.5 inches per year.

Comparisons in drawdown values one foot from the well between those calculated by the Weber equation and those calculated by the Walton equation,using the same values for w at all various pumping rates, showed that the differences in results are not significant.

By using Walton's model, a comparison was made of the impact that differences in recharge rates would have on drawdowns at various pumping rates (Table 23) and consequently on the well spacing required to maintain the water table at a predetermined depth at the midpoint between wells (Table 24). Comparative calculations were made with w = .055 gallons/day/ft.^{2} or 32 inches per year at an assumed recharge rate from wastewater of 50 percent of the application rate of one inch

TABLE 23: COMPARISON OF DRAWDOWNS AT DIFFERENT ASSUMED RECHARGE RATES WITH WALTON'S MODEL

	50% Infiltration			75% Infiltration		
	Transmissibility = 9,350 gpd/ft.					
	Drawdown in Feet For Pumping Rates			Drawdown in Feet For Pumping Rates		
Distance From Well in Feet	50 gpm	100 gpm	300 gpm	50 gpm	100 gpm	300 gpm
1	7.6	16.0	52.2	6.2	15.6	51.0
10	4.7	10.4	35.3	3.8	10.0	34.1
100	1.9	4.7	18.4	1.5	4.6	17.2
1000	.0	.2	2.7	.0	.1	1.9

	Transmissibility = 11,075 gpd/ft.					
	Drawdown in Feet For Pumping Rates			Drawdown in Feet For Pumping Rates		
Distance From Well in Feet	50 gpm	100 gpm	300 gpm	50 gpm	100 gpm	300 gpm
1	6.3	13.5	44.1	6.2	13.2	43.1
10	4.0	8.7	29.8	3.8	8.4	28.8
100	1.6	4.0	15.5	1.5	3.9	14.6
1000	.0	.2	2.3	.0	.1	1.6

TABLE 24: COMPARISON OF WELL SPACING WITH INFILTRATION OF WASTEWATER AT 50% AND 75% OF APPLICATION RATE

Trans-missibility gpd/ft.	Available Drawdown-Ft.	Pumping Rate-gpm	Distance Between Wells - Feet		Number of Wells per Square Mile	
			50% filtration*	75% filtration**	50% filtration*	75% filtration**
<5,000	0					
5,000	0					
7,500	5	25	912	822	42.6	50.3
10,000	10	65	1,472	1,354	16.4	19.4
12,500	15	120	2,000	1,838	8.9	10.5
15,000	20	200	2,580	2,375	5.3	6.3
17,500	22.5	240	2,828	2,600	4.4	5.2
20,000	25	300	3,162	2,908	3.5	4.2
22,500	30	390	3,606	3,316	2.7	3.2
25,000	33	500	4,802	3,755	2.1	2.5
27,500	35.5	590	4,434	4,080	1.8	2.1

* Based on formula $A = \frac{Q}{w}$ with w = .055 g/d/ft.^{2}

** Based on formula $A = \frac{Q}{w}$ with w = .065 g/d/ft.^{2}

per week for 43 weeks; and with w = .065 gallons/day/ft.^{2} or 42.8 inches per year at an assumed recharge rate from wastewater at 75 percent of the application rate of one inch per week for 43 weeks.

It is clear that significant differences in drawdown response and required well spacing will result from different recharge values resulting from wastewater application. For the purpose of regional analysis to demonstrate the physical feasibility for groundwater system management, a recharge rate of 50 percent of the wastewater application rate of one inch per week for 43 weeks was used. If the recharge rate, the rate of application or the period of application varies from those assumed rates, the drawdown effects and the well spacing determinations will need to be modified correspondingly.

Regional Patterns

Assessment of the physical feasibility for groundwater system management to an adequate degree to substantiate that there is a reasonable potential for operational control of water table levels and of groundwater flow patterns requires that regional patterns of hydrologic factors relevant to such control measures be established. Geologic relationships and correlations define the physical framework within which hydrologic factors are inserted and extrapolated to determine such distributional patterns. Distributional maps on the thickness of zone A and depth to groundwater along with permeability characteristics determined by well tests were used to define probable regional patterns of transmissibility and available drawdown which constitute the basic parameters for assessing the feasibility for drainage wells, the maximum pumping rates that can be anticipated, distance drawdown relationships and anticipated maximum spacings for drainage wells and tiles to achieve the desired control.

Regional patterns of transmissibility within the pattern area are a function of the operational thickness of the aquifer and permeability according to the expression $T = tP$ where T is transmissibility in gallons/day/foot, t is saturated thickness of the aquifer and P is permeability in gallons/day/ft.^{2}

The operational thickness of the aquifer (t_o) is the saturated thickness of zone A during project operation, i.e., the stabilized level of the water table at the intersection of pumping cones. In determining t_o, a minimum depth of 10 feet to water was assumed for the project area. In areas where depth to water is currently less than 10 feet, the operational thickness was determined by subtracting 10 feet (stabilized level at intersection of pumping cones) from the total thickness for zone A. In areas where the present depth to groundwater is greater than 10 feet, the operational thickness was determined by subtracting the present depth to groundwater from the total thickness of zone A. The resulting map (Figure 14) is the saturated thickness of zone A during management operations.

Regional patterns of permeability were arbitrarily projected on the basis of the pumping test results. In those areas where the operational thickness is greater than 30 feet, a permeability of 443 gallons/day/ft.^{2} was projected as the regional permeability. In areas where the operational thickness is less than 30 feet, a permeability of 374 gallons/day/ft.^{2} was projected. Based on the relationship $T = t_o \times P$, a pattern map of the regional distribution of transmissibility was constructed (Figure 15).

In determining the maximum allowable pumping rates for water level control wells, it is necessary to establish the maximum drawdown for the well. The drawdown level should be maintained above the top of the well screen to allow for probable well loss and the future clogging of well screens. According to the well test analysis report on well 70-A by Dr. Keck, screening of about one-third of the aquifer thickness utilizes about 90 percent of the yield theoretically available. For purposes of determining the drawdown available at various locations within the system, the available drawdown was determined by the following relationship: $S_A = t_o - (1/3\ t_o = B)$, where S_A = the available drawdown, t_o = operational thickness, and B - a five-foot buffer zone above the top of the screen. A minimum screen length of 10 feet was assumed for those areas where the aquifer is more thinly developed. Therefore, in areas where t_o is 15 feet thick or less, the available drawdown (S_A) will be equal to 0 and an area limit is defined for the use of wells to affect drainage. Also in areas where S_A is small and transmissibility is low, well yields would be small and a correspondingly larger number of wells would be required to maintain the water table at design levels. In areas of thin sand cover where water table control cannot be efficiently or effectively applied by discharge wells, control can be established by the use of drain tiles. The available drawdown is shown on Figure 16.

Analysis of relationships that are developed in this study are based on the interior well premise, that is, that no groundwater inflow is involved. Groundwater inflow will be a factor along the margins of the project as finally defined.

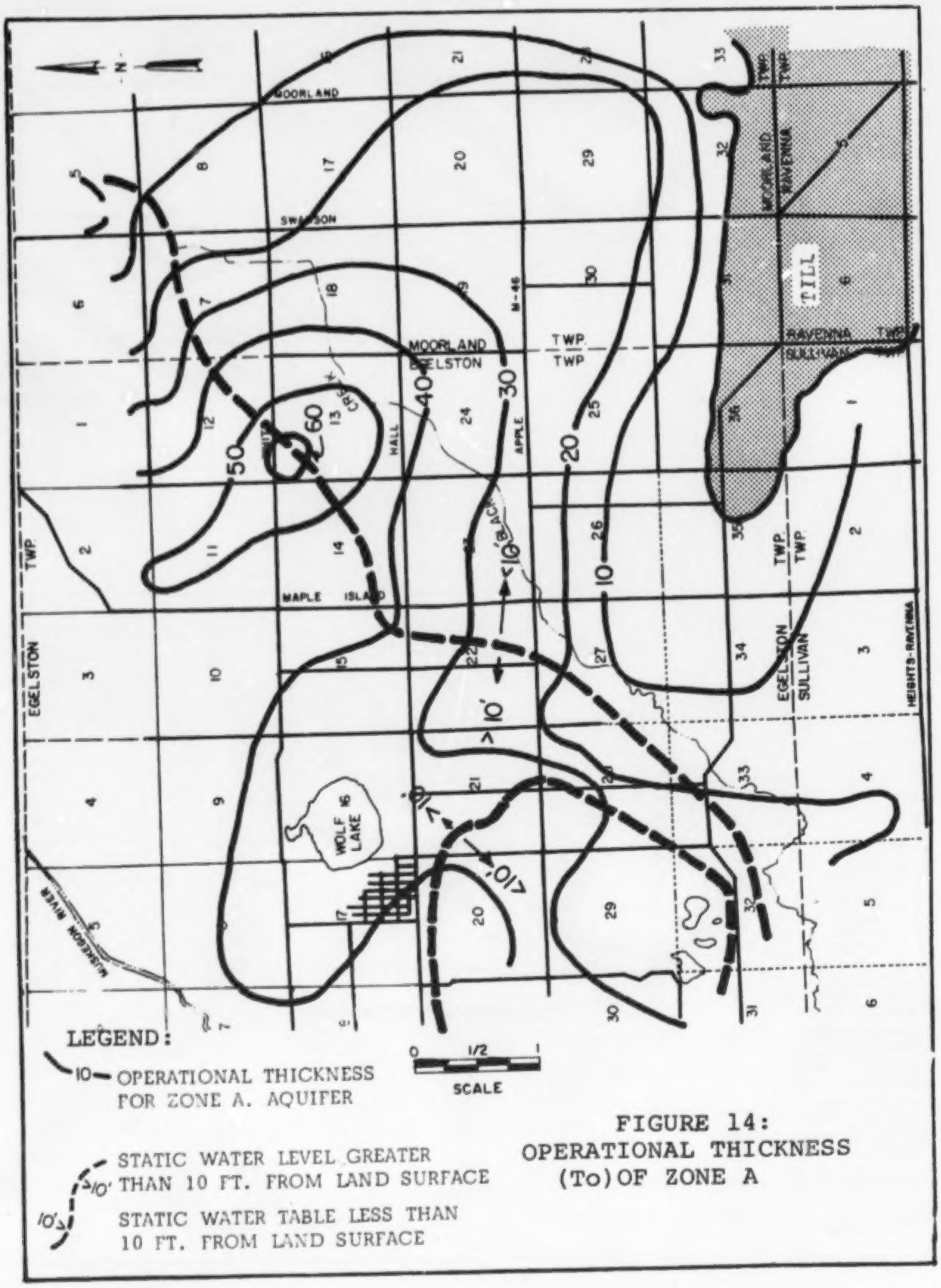
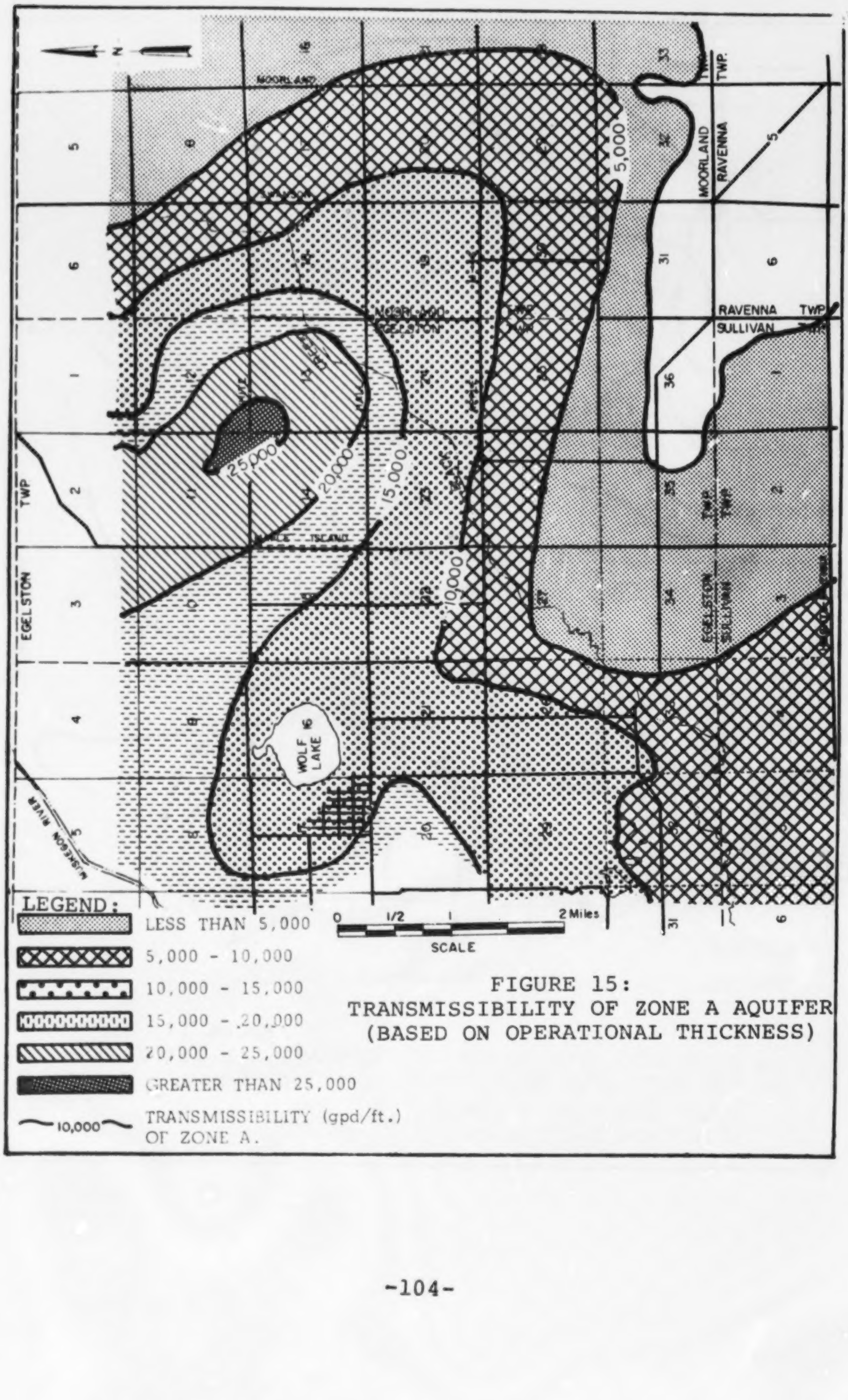
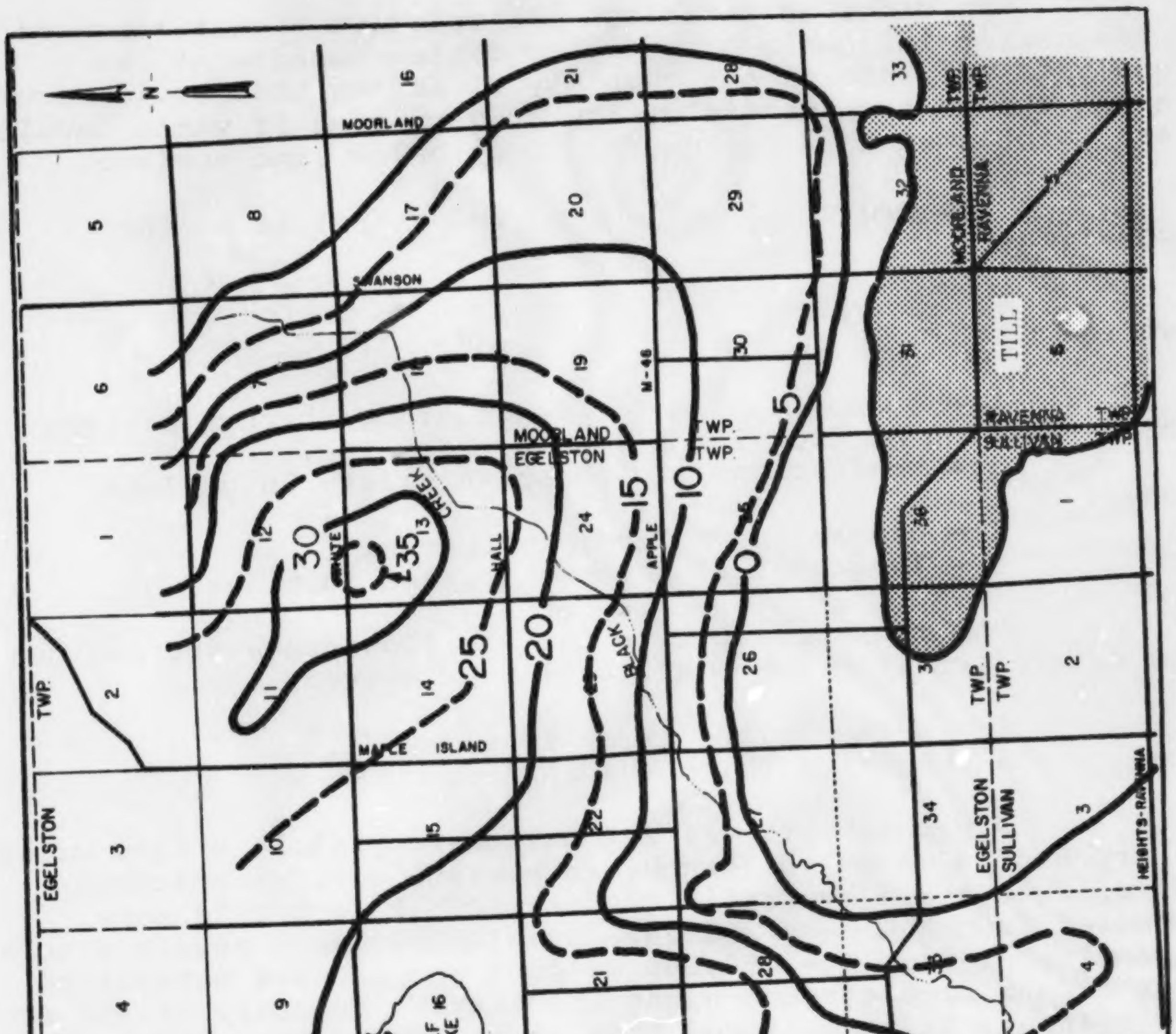

N
MOORLAND
SWANSON
MOORLAND TWP.
EGELSTON TWP.
RAVENNA TWP.
SULLIVAN TWP.
MOORLAND RAVENNA
EGELSTON SULLIVAN
HEIGHTS-RAVENNA
EGELSTON TWP
TILL
MAPLE ISLAND
APPLE
HALL
M-46
CREEK
BLACK
WOLF LAKE
MUSKEGON RIVER
60
50
40
30
20
10
>10'
<10'
LEGEND:
10 OPERATIONAL THICKNESS FOR ZONE A. AQUIFER
>10' STATIC WATER LEVEL GREATER THAN 10 FT. FROM LAND SURFACE
<10' STATIC WATER TABLE LESS THAN 10 FT. FROM LAND SURFACE
0 1/2 1
SCALE

FIGURE 14:
OPERATIONAL THICKNESS
(To) OF ZONE A



N
MOORLAND
MOORLAND TWP.
RAVENNA
RAVENNA TWP.
SULLIVAN TWP.
EGELSTON TWP.
EGELSTON
SULLIVAN
WOLF LAKE
MUSKEGON RIVER
5,000
10,000
15,000
20,000
25,000
0
1/2
1
2 Miles
SCALE
LEGEND:
LESS THAN 5,000
5,000 - 10,000
10,000 - 15,000
15,000 - 20,000
20,000 - 25,000
GREATER THAN 25,000
10,000 TRANSMISSIBILITY (gpd/ft.) OF ZONE A.

FIGURE 15:
TRANSMISSIBILITY OF ZONE A AQUIFER
(BASED ON OPERATIONAL THICKNESS)



N
MOORLAND
SWANSON
MOORLAND
EGELSTON
TWP.
TWP.
WHITE
CREEK
HALL
APPLE
BLACK
M-46
MAPLE ISLAND
EGELSTON
TWP.
WOLF LAKE
MUSKEGON RIVER
MOORLAND
RAVENNA
TWP.
TWP.
TILL
RAVENNA
SULLIVAN
TWP.
TWP.
EGELSTON
SULLIVAN
HEIGHTS-RAVENNA
35
30
25
20
15
10
5
0
5
8
16
21
28
33
17
20
29
32
6
7
18
19
30
31
1
12
13
24
25
36
2
11
14
23
26
35
3
10
15
22
27
34
4
9
16
21
28
33
5
8
17
20
29
32
31
6

LEGEND:

S_A = To -(1/3 To +B)

To = OPERATIONAL THICKNESS

1/3 To = SCREEN LENGTH FOR 90% PRODUCTIVITY (ASSUMED MINIMUM = 10 Ft.)

B = BUFFER ZONE ABOVE TOP OF SCREEN (ASSUMED MINIMUM = 5 Ft.)

S_A = O WHERE To = 15 SEE EX. 7

—5— AVAILABLE DRAWDOWN

0 1/2 1

SCALE

FIGURE 16:
AVAILABLE DRAWDOWN

In order to establish the relative significance of groundwater inflow in groundwater system management, an analysis was made of the quantity of inflow that would occur along the eastern margin of the project area if water levels are maintained at a depth of 10 feet below land surface.

The amount of inflow can be determined by the equation:

$$Q = TIL$$

where:

Q = quantity of water percolating through a given cross-section of flow in gallons per day
T = coefficient of transmissibility in gallons/day/foot
I = hydraulic gradient in feet/mile
L = length of flow cross section in miles

The transmissibility for the flow cross-section can be determined from the equation $T = PM$ where:

P = permeability in gallons/day/ft.^{2}
m = aquifer thickness in feet

A permeability of 374 gallons/day/ft.^{2}, a flow cross-section of 4 miles in length, an average aquifer thickness of 25 feet and a hydraulic gradient of 12 feet/mile were applied from the maps and data available. As a result a total quantity of flow Q = 450,000 gallons per day was determined for a four mile stretch along the eastern boundary of the project area. It is believed that an inflow of this order of magnitude can be readily accounted for by a relatively small increase in the number of drainage wells or by appropriate spacing of drainage tiles.

Inflow from Black Creek must also be considered in final design. Under the assumed conditions of site operations, the upper part of Black Creek could function as a losing stream providing an inflow of water that would have to be removed by the drainage facilities. No data is available to provide a reasonable estimate of the quantity of inflow that could be expected to be provided through the bed of Black Creek. Also inflow from this source could be avoided by lining the channel in some manner to prevent infiltration.

Use of Drainage Wells

Determination of distance-drawdown relationships of discharge wells for the range in transmissibility estimated within the project area were based on the Walton model. Graphical representations of the distance-drawdown relationships at the pumping rate adjusted to the available drawdown are shown on Figures 17 through 25, inclusive. A recharge rate of 32 inches per year has been assumed in the determinations.

Because the mathematical solution of the Walton formula does not allow the determination of the maximum radius of the cone, it was necessary to calculate this on the basis of the area of the cone formula:

$$A = Q/w$$

where:

A = area of cone
Q - quantity of water removed in gallons per day
w = recharge rate (0.55 gallons/day/ft.^{2})

The maximum radius of the cone (Rmax) represents the distance to which the cone from a discharge well will develop while pumping at the rate determined by the allowable drawdown. Theoretical spacing between wells is, therefore, equal to twice the radius.

Spacing between wells within the various transmissibility ranges at conditions of 50 percent and 75 percent infiltration of the application rate are given in Table 24. The figures represent the spacing between wells when adjoining cones abut at the point of zero drawdown. Therefore, as it will be necessary under operating conditions to provide for overlap of the cones, the distances in Table 24 represent the maximum spacing between wells. According to the data provided in Table 24, spacing distances for control wells range from about 900 feet for wells pumping at 25 gallons per minute to 4400 feet for wells pumping at the rate of nearly 600 gallons per minute.

The number of wells required to discharge the quantity of water recharged per square mile has been estimated from the $A = Q/w$ relationship or where the area of the individual pumping cone is determined, in terms of the gallons per day pumped by that well.

The number of wells within a square mile required to discharge the water recharged within that square mile is determined by the relationship: $N = A/Ac$ where:

N = the number of wells
A = total area
Ac= area of the cone

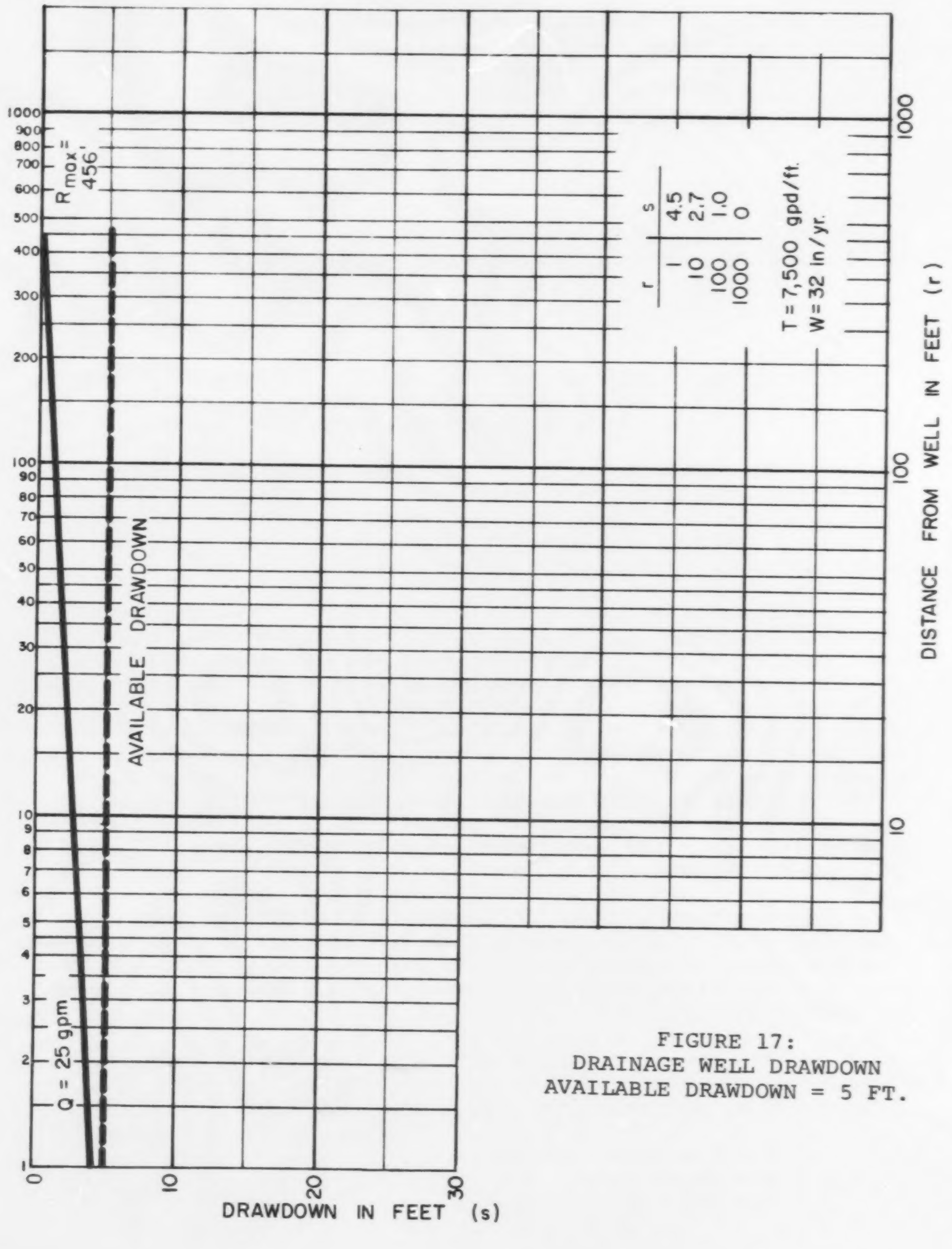
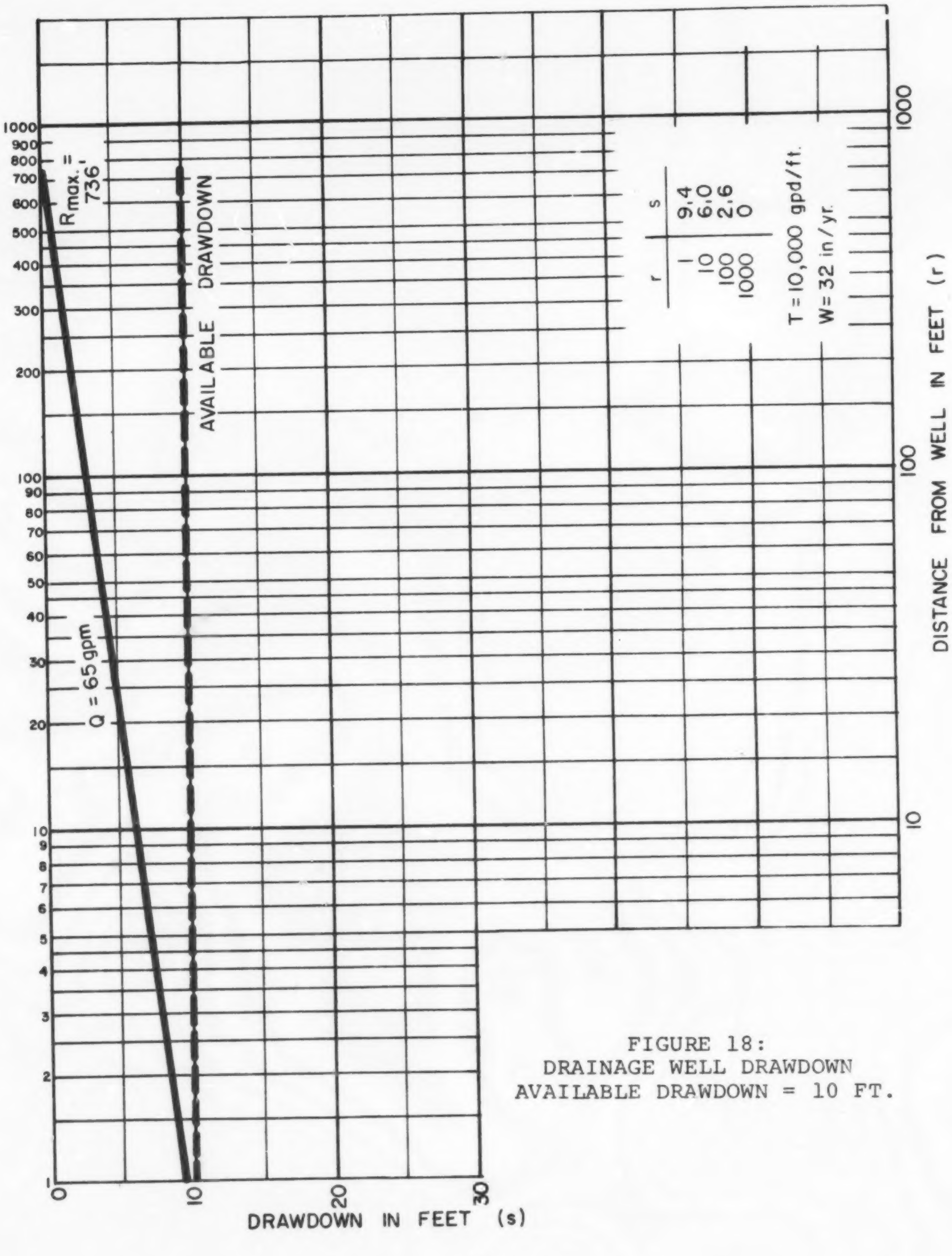


FIGURE 17:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 5 FT.



r	s
1	9.4
10	6.0
100	2.6
1000	0

FIGURE 18:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 10 FT.

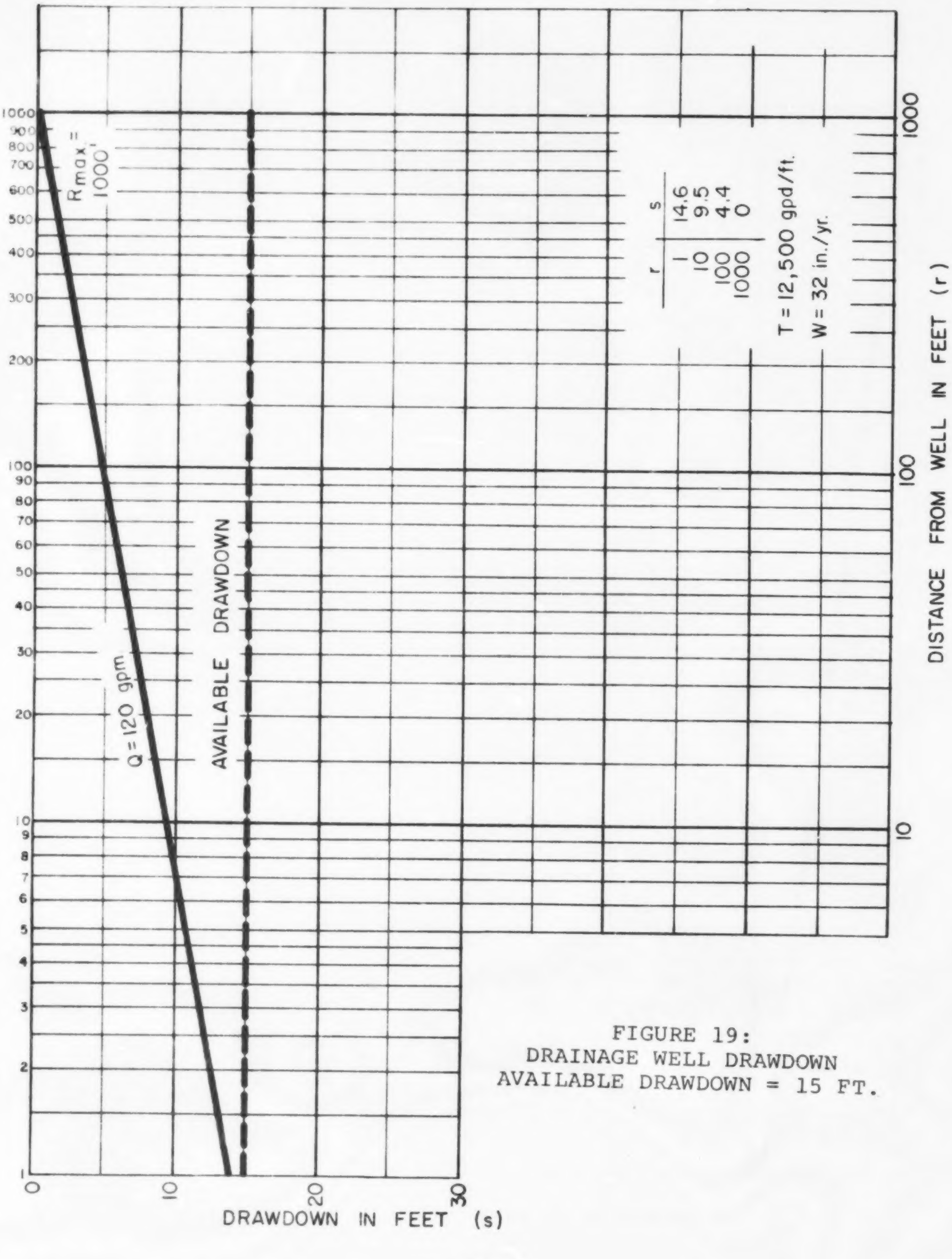


FIGURE 19:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 15 FT.

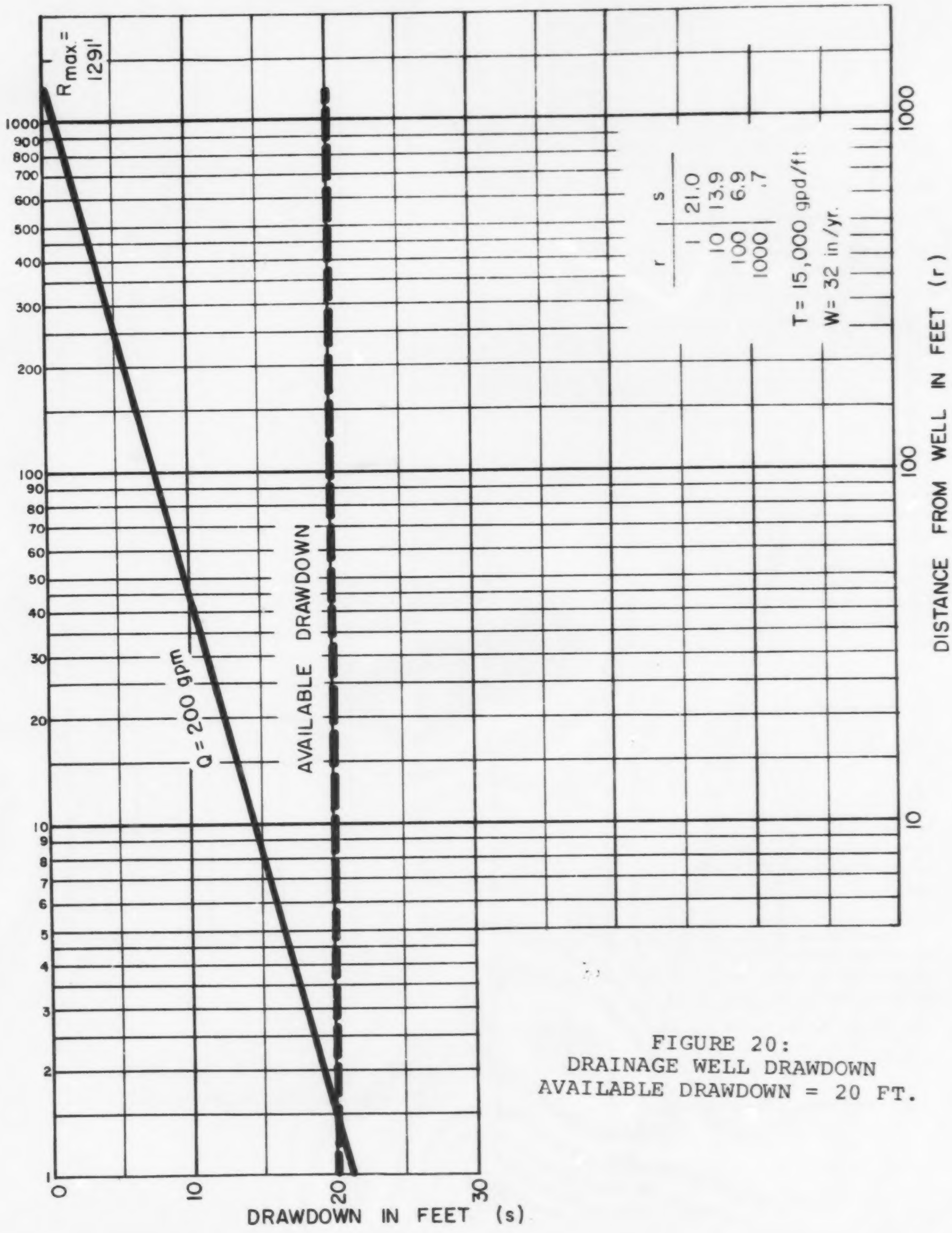


FIGURE 20:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 20 FT.

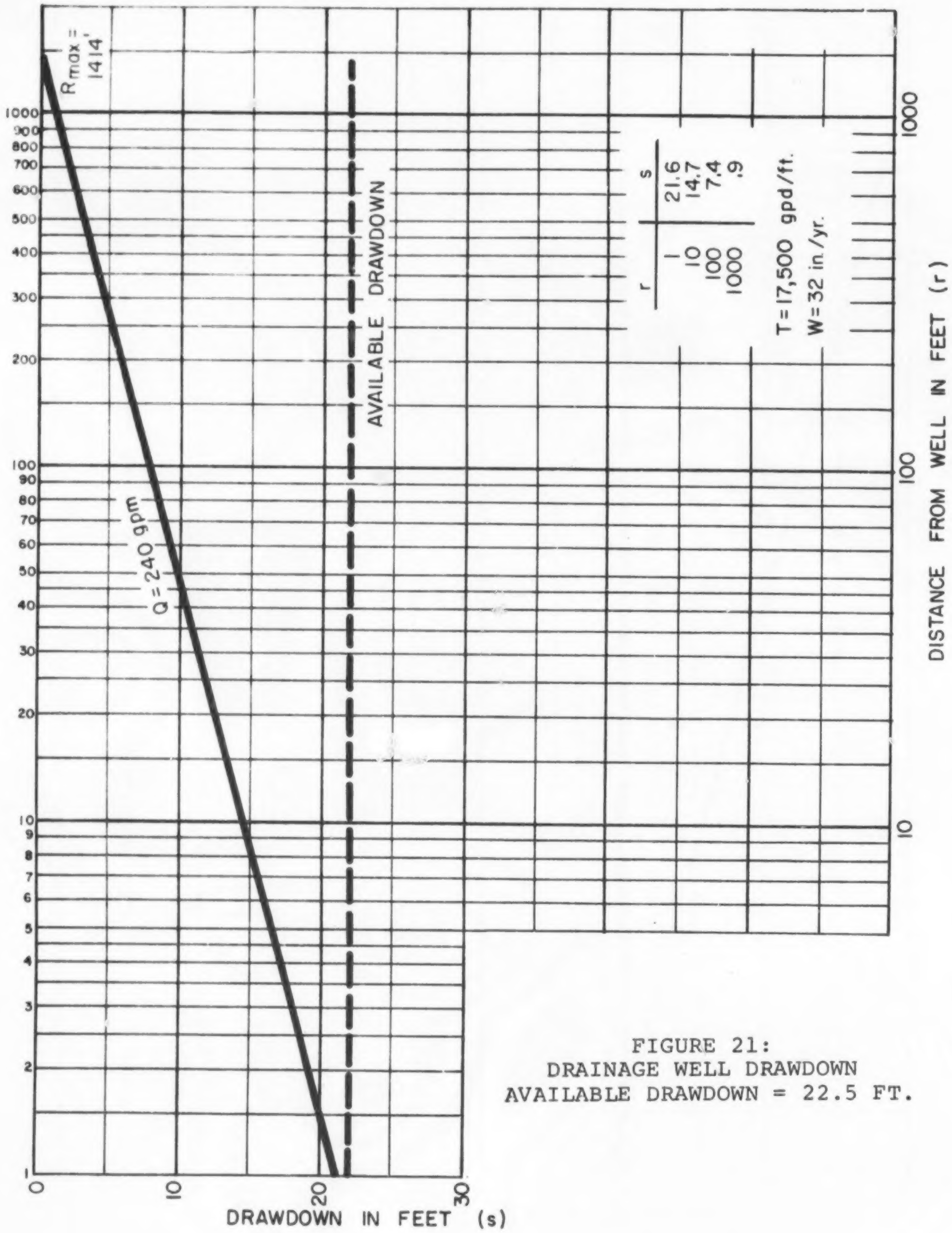


FIGURE 21:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 22.5 FT.

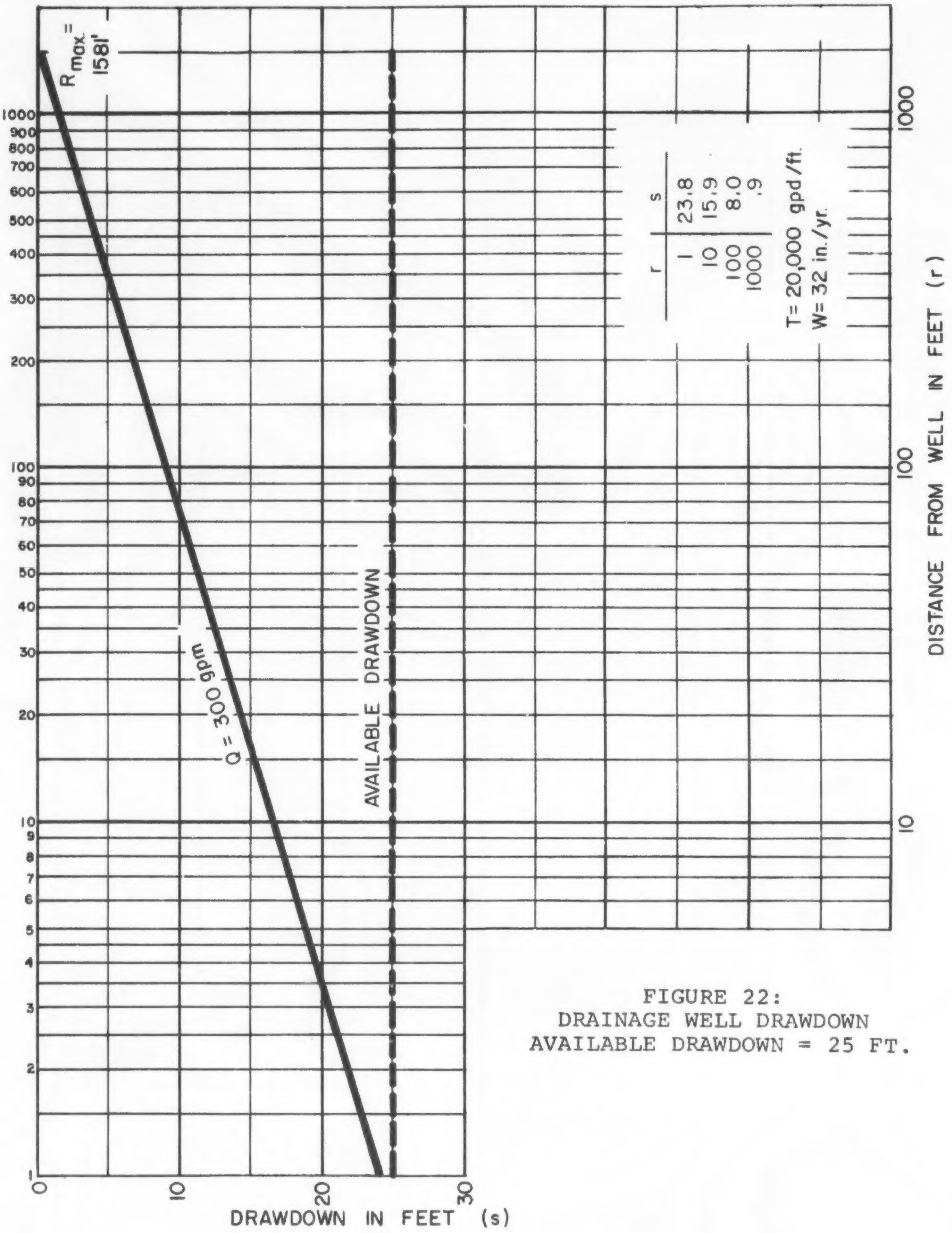


FIGURE 22:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 25 FT.

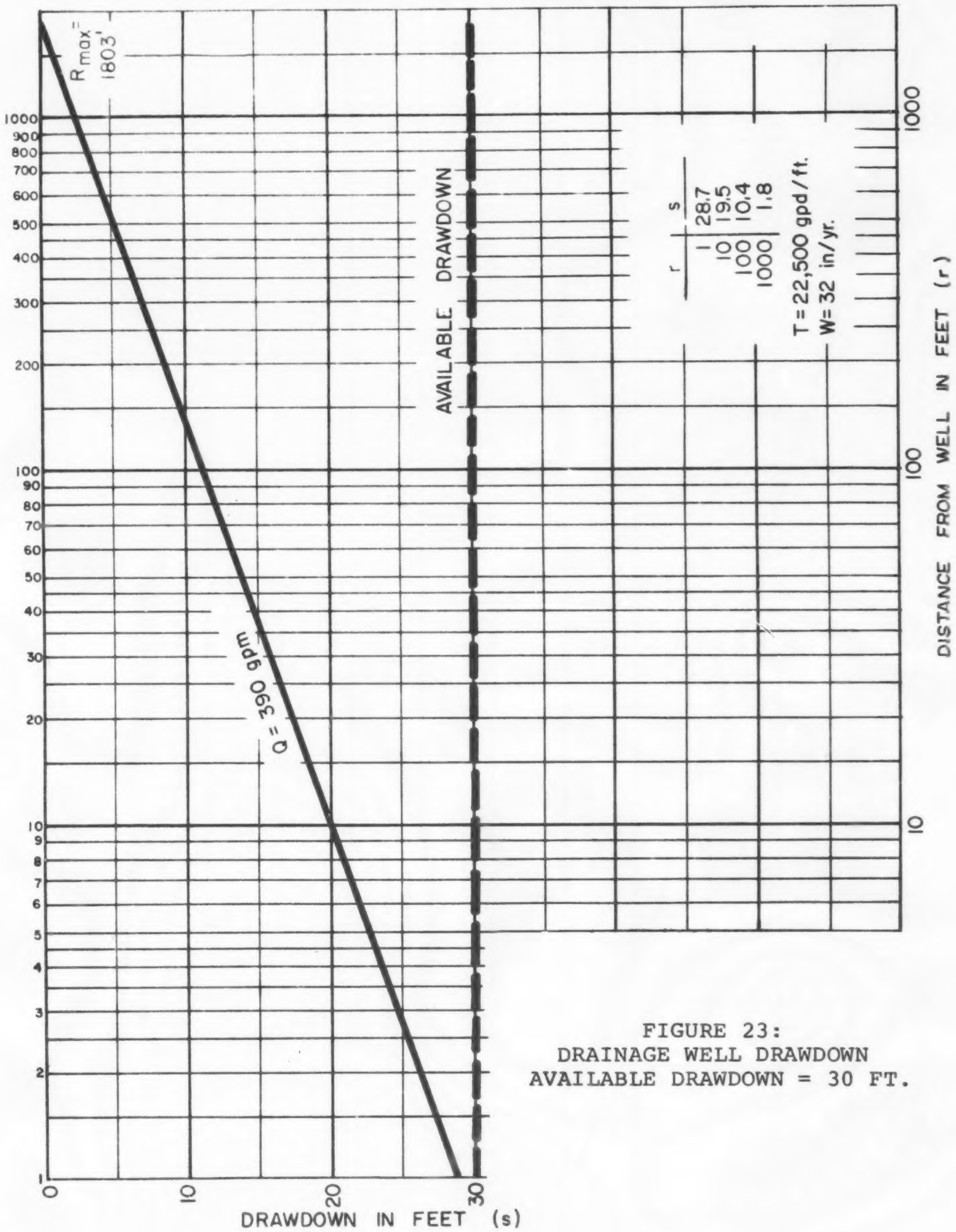
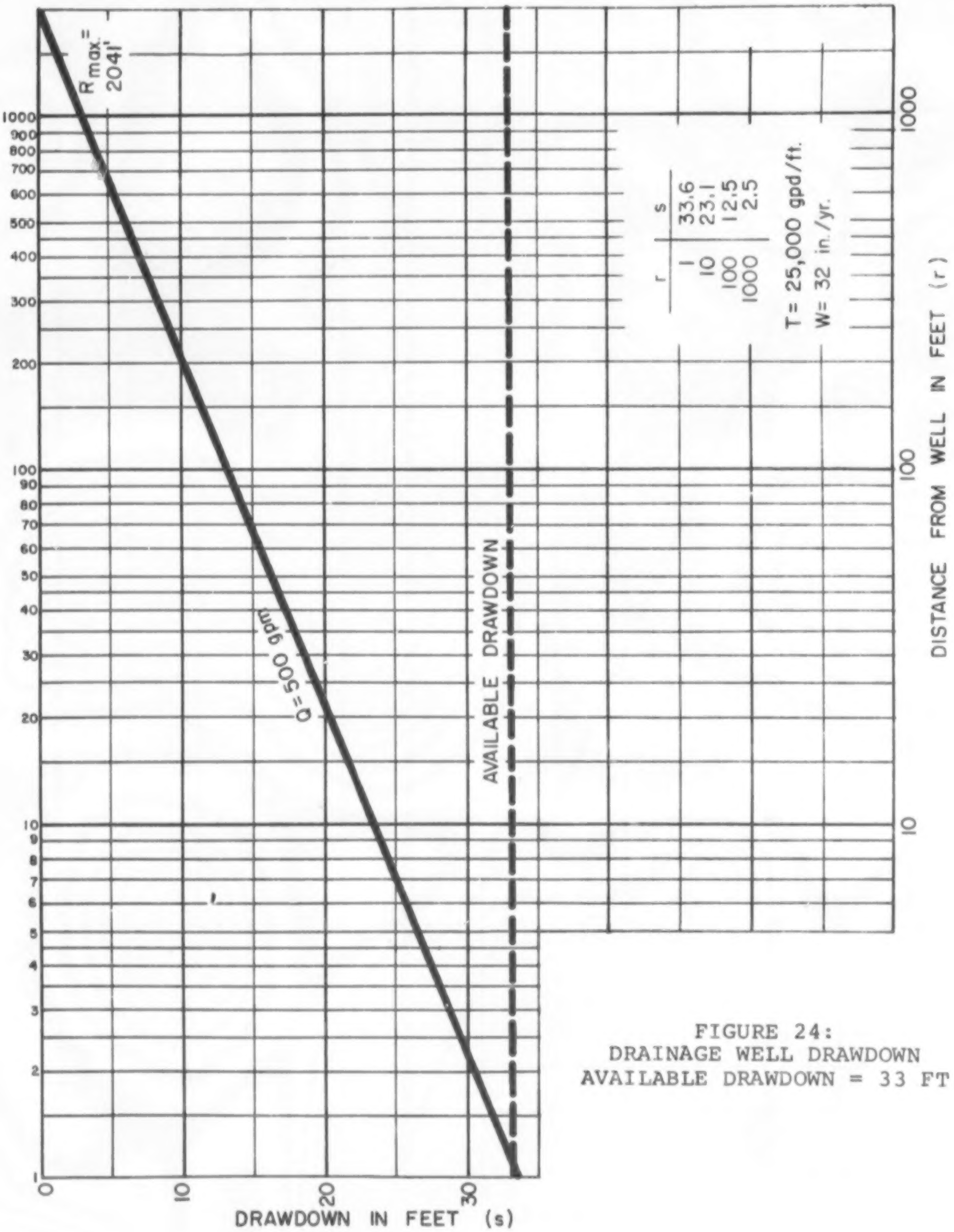


FIGURE 23:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 30 FT.



r	s
1	33.6
10	23.1
100	12.5
1000	2.5

FIGURE 24:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 33 FT.

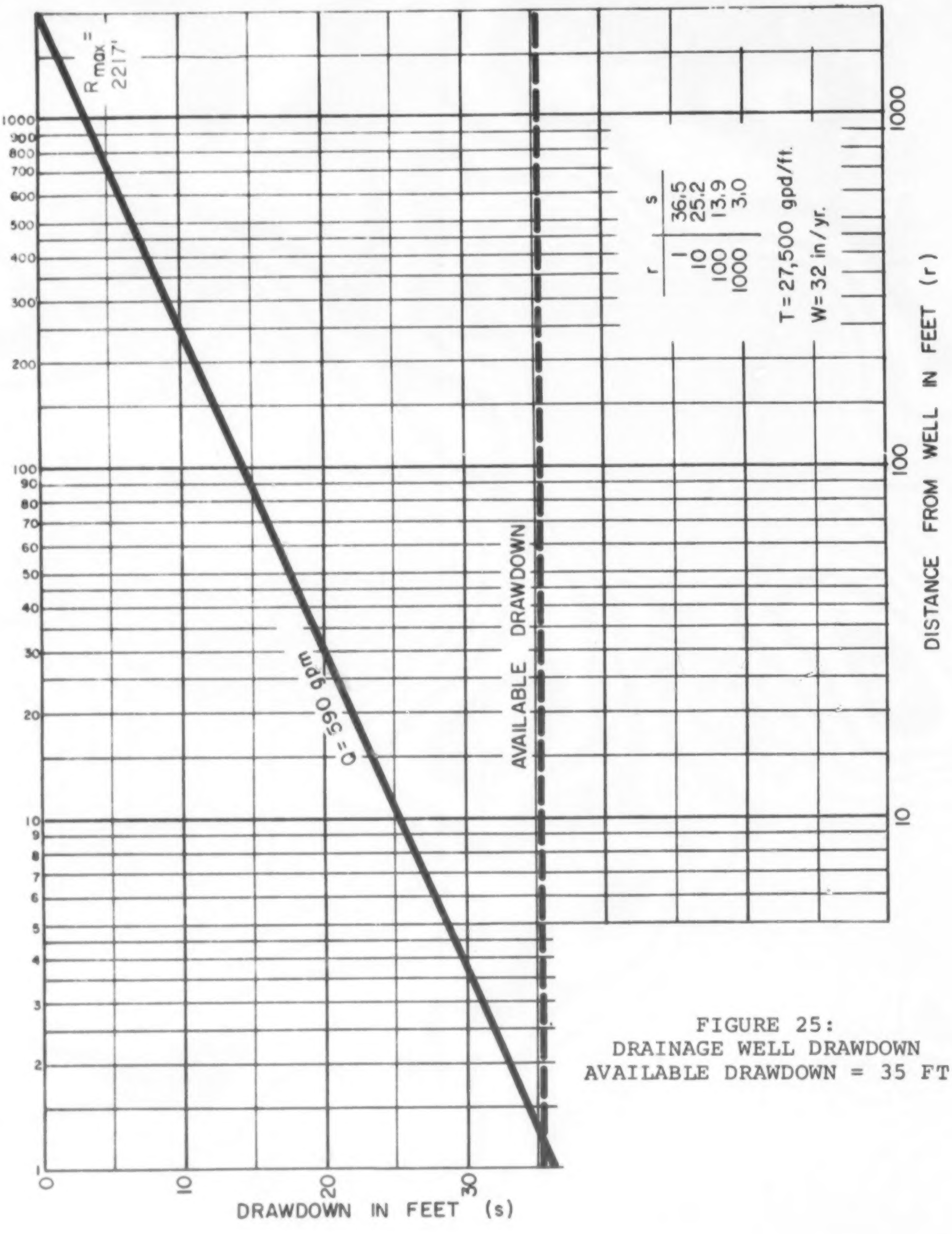


FIGURE 25:
DRAINAGE WELL DRAWDOWN
AVAILABLE DRAWDOWN = 35 FT.

The number of wells required for 50 percent and 75 percent infiltration of the application rate are given in Table 24.

These determinations imply that all of the area is included within the area of the cone of influence of the pumping wells. Because the areas of the cones are circular in shape, the geometric relationships will not allow this without overlap of cones. The results presented, therefore, represent the minimum number of wells required per square mile to handle the recharge. The data developed are, however, useful in making relative comparisons between relative investments required for drainage by wells and drainage by tiles as aquifer conditions vary within the project area.

Use of Drainage Tiles

Spacing of tile drains can be determined by two basic formulas, the Donnan formula and the radial-flow formula (Israelson and Hansen, 1962). The Donnan formula is based on the assumption of lateral flow to a drain with an impermeable stratum at some known depth below the drain. The radial-flow formula is based on radial flow to a tile drain with an impermeable stratum at great depth or absent.

Factors affecting these formulas are permeability P, distance to barrier stratum (Donnan formula only), drainage coefficient D, and diameter of tile d (radial-flow formula only).

Permeability used in the comparison was obtained by well testing and is the average permeability of the aquifer. The permeability needed for proper analysis is the permeability of the soil to the depth of the drains. Geologic evidence suggests that these permeabilities are likely to be lower than those derived from well testing.

The quantity of water to be drained (Q and q) by the tile is related to the drainage coefficient D. D largely depends on the two factors of rainfall intensity and soil density. In our case, D is also related to the daily rate of application of watewater (q) and the travel time through the soil to the drain in 24 hours. Tile spacings must be designed to handle the higher intensity rainfall in 24 hours (example the 5" storm). It is assumed when rainfall occurs irrigation of wastewater will cease. Therefore D is directly related to the higher hydraulic loading either from rainfall or irrigation. In the comparison it was assumed that the higher hydraulic loading was from rainfall. The q used was estimated to be 1%

of the annual rainfall estimated to be 32" per year (.225 gal/day/ft.^{2}).

A comparison of the formulas was made to determine the depth at which the barrier stratum no longer affects the Donnan formula. Beyond this critical depth the radial-flow formula should be used to determine the tile spacing. Several diameters of tile were used as this is an important parameter in the formula. The comparison of the relation of H to Q as determined by the formula is shown on Figure 26. In the comparison it was assumed that the tile was 50% filled. Distance to the barrier stratum, H, was measured from the groundwater surface.

The critical depth (Hc) occurs when the total flow Q derived from both formulas is equal. Beyond the critical depth, the Donnan formula no longer applies for determining tile spacing. The radial-flow formula gives only one spacing for a given hydraulic gradient as equilibrium conditions occur. Data are given for the comparison on Table 25. As tile diameter increases, Hc decreases.

Spacings for the tiles are shown in Table 26. Calculations for the spacing derived from the radial-flow formula are also included. Spacing for various diameters of tile were incongruent and an average spacing is presented. These inconsistencies are thought to be caused by the method of the derivation of the radial-flow formula as the depth of the water, h, in the tile is also a function of the Manning equation.

Dewatering Time

A preliminary determination of the time required for dewatering using the same well spacing that would be required to maintain the water table at an operational level of 10 feet was made in order to evaluate the potential significance of this factor to system operation. The estimate was made in terms of the time required to remove by pumping, the volume of water involved assuming that it was instantaneously available from the aquifer.

The following times were determined in arriving at the estimate:

(1) Time for dewatering to the 10 foot level assuming saturated conditions to land surface.

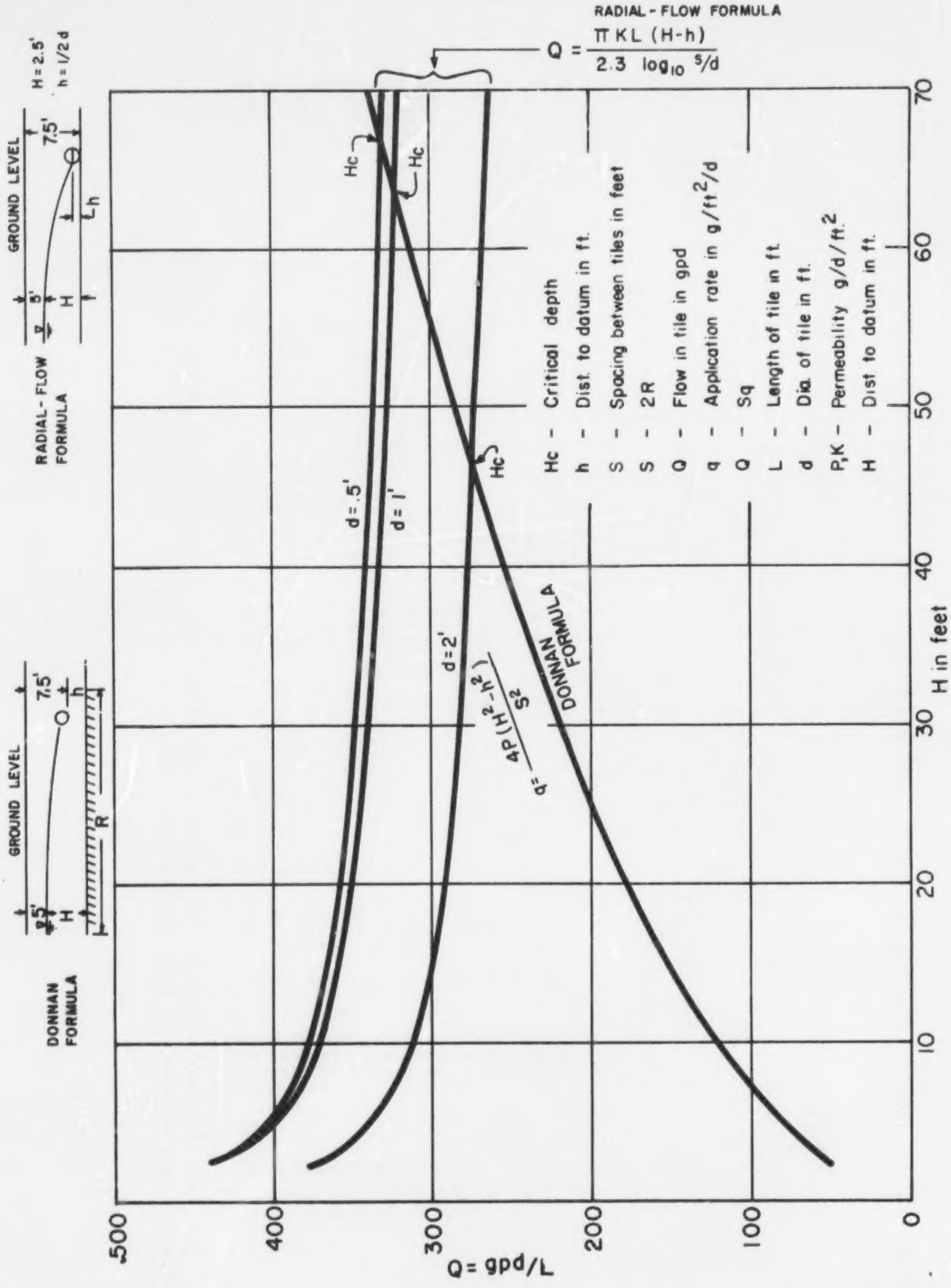


FIGURE 26: DONNAN AND RADIAL-FLOW FORMULAS
(COMPARISON FOR CRITICAL DEPTH)

TABLE 25: TOTAL FLOW PER UNIT LENTH OF TILE BY DONNAN AND RADIAL FLOW FORMULAS

Donnan Formula

$$S^2 = \frac{4P(H^2-h^2)}{q}$$

$$S^2 = \frac{4(374)\ (H^2-h^2)}{.225\ \text{gpd/ft.}^2}$$

Radial-Flow Formula*

$$Q = \frac{\pi kL(H-h)}{2.3\ \log_{10} s/d}$$

$$Q = \frac{3.14(374)(1)(H-h)}{2.3\ \log_{10} s/d}$$

H Ft.	h Ft.	S Ft.	Q=Sq gpd/L	Q=gpd/L d = .5 ft/ H-h=2.25 ft.	Q=gpd/L d=1 ft. H-h=2.0 ft.	Q=gpd/L d= 2 ft. H-h=1.5 ft.
2.5	0	203	52	440	443	381
5	2.5	353	79	403	401	341
7.5	5.0	456	103	388	384	324
10	7.5	539	121	379	373	315
20	17.5	789	177	359	352	295
30	27.5	978	219	349	341	285
40	37.5	1135	255	342	335	278
50	47.5	1273	286	337	329	273
60	57.5	1398	314	333	325	269
70	67.6	1511	340	330	321	265

* p. 370 Israelson, O. W. and V. E. Hansen, Irrigation Principles and Practices, John Wiley and Sons, Inc., New York, 3rd ed., 1962.

TABLE 26: SPACING OF TILE DRAINS RELATED TO SATURATED THICKNESS

Saturated Thickness Ft.	Flow per Linear Foot of Drain** gpd	Spacing Between Tiles Ft.		
		Diameter of Tile		
		2 feet	1 foot	1/2 foot
2.5	50	203	203	203
5	79	353	353	353
7.5	103	456	456	456
10	121	539	539	539
20	177	789	789	789
30	219	978	978	978
40	255	1135	1135	1135
50	286	*1560	1273	1273
60	314	*1560	1398	1398
70	340	*1560	*1560	*1560

*Radial Flow Formula Applies for that Diameter

**Based on Donnan Formula

Trial and Error Solution of Radial-Flow Formula for Tile Spacing:

$$Q = \frac{\pi kL(H-h)}{2.3 \log_{10} s/d}$$

where $Q = Sq$
$h = .5d$

$$S\log_{10} s/d = \frac{\pi kLH}{2.3q} - .5d\pi k$$

2 feet diameter	1 foot diamteter	1/2 foot diameter
S = 1556 feet	S - 1589 feet	S - 1542 feet

Average Spacing = 1560 feet

(2) Time for dewatering within the cone of depression around the pumping well below the stabilization level.

(3) Time for pumping additional water added to the system by rainfall during the dewatering process.

Calculations were made for conditions of pumping at 500 gallons per minute and at 25 gallons per minute which are representative of the range of the pumping rates that are likely to exist at maximum available drawdowns interpreted for the project area. A specific yield of .20 was assumed in the calculations. This figure obtained during well test 70-A should represent the maximum effective porosity.

At a dewatering rate of 500 gallons per minute:

(1) Dewatering 10 feet of aquifer:

Time = Volume/pumping rate

$$= \frac{\text{Area of cone x depth x specific yield x 7.48 gal.ft.}^3}{\text{pumping rate x 1440 minutes/day}}$$

$$= \frac{13.09 \times 10^6 (Q/w) \times 10 \times 0.20 \times 7.48}{500 \times 1440}$$

= 272 days

(2) Dewatering the cone of depression:

Volume = $2\pi\bar{r}A$ (Simpson's rule)

$$\text{Time} = \frac{2.28 \times 10^7 \times 7.48 \times 0.2}{500 \times 1440}$$

= 47 days

(3) Rainfall accretion:

$$\text{Time} = \frac{\text{pumping period x area of cone x rate per day/ft.}^3}{\text{pumping rate x 1440 minutes/day}}$$

a. For 272 + 47 = 319 days of rainfall
time = 104 days

b. For 104 days of rainfall
time = 34 days

c. For 34 days of rainfall
time = 11.0 days

d. For 11 days of rainfall
time = 3.6 days

e. For 3.6 days of rainfall
time = 1.2 days

f. For 1.2 days
time = 0.4 days

Total dewatering time = (1) + (2) + (3)a - f = 473 days.

At a dewatering rate of 25 gallons per minute:

(1) Dewatering 10 feet of aquifer

$$\text{Time} = \frac{\text{area of cone x depth x specific yield x 7.48 gallons/ft.}^3}{25 \text{ x } 1440}$$

= 272 days

(2) Dewatering the cone of depression

Volume = $2\pi\bar{r}A$ (Simpson's rule)

Time = volume/pumping rate

= 8 days

(3) Rainfall accretion:

a. For 280 days of rainfall
time = 92 days

b. For 92 days of rainfall
time = 30 days

c. For 30 days of rainfall
time = 9.8 days

d. For 9.8 days of rainfall
time = 3.2 days

e. For 3.2 days of rainfall
time = 1 day

Total dewatering time = (1) + (2) + (3)a-e = 416 days.

Therefore it is estimated that dewatering of the aquifer saturated to land surface to a depth of 10 feet below land surface will require more than 400 days assuming a specific yield of 0.20 for the aquifer and the use of well spacing where the water level at midpoint between adjacent wells is at a depth of 10 feet below land surface.

The time estimate may be too large because the geometric relations of the application area is likely to require overlapping of cones of depression to adequately influence the entire area and because the specific yield used in the calculations is the probable maximum specific yield that can be anticipated for the aquifer.

The estimate might be too low because time for release of the water from the area dewatered is not considered in the calculations. However it is reasonable to assume that the time for dewatering is likely to be in terms of months rather than in days or weeks.

The dewatering time can be reduced by (a) increasing the number of discharging wells in the site area by reducing the spacing of water level control wells, or (b) by inserting additional temporary wells to increase the pumpage rate during the dewatering period.

The above calculations refer only to the area in which water table is currently above the 10 foot depth level. In the parts of the project area where water table is in excess of 10 feet, only the volume of water within the cone and the accretionary rainfall during cone development need to be considered. In these areas the dewatering time is likely to be 1/2 to 2/3 less than the estimates given above and be in terms of weeks.

Management Implications

The data and information acquired in this study are believed adequate to demonstrate that site management of the groundwater system to stabilize water table levels at desired depths through the use of drainage wells and tiles is a physical feasibility. However, because of regional variations in thickness of the zone A aquifer and in depth to the water table, management programs must be designed in terms of the limitations and constraints as they are likely to exist within the project area. The patterns of hydrogeologic conditions developed in this study should provide the basis for preliminary definition of broad design alternatives. Because of the need for broad extrapolations in the analyses due to data limitations, the results presented in this study must not be considered as precise determinations.

The analysis of the physical feasibility for project area management indicates that there are five broad subareas within the project area outlined on Figure 27 which relate to management operations. These subareas are summarized briefly as follows:

Subarea 1 - Areas with less than 15 feet saturated aquifer thickness; water table less than five feet below land surface. In this subarea there is no opportunity for the use of wells for drainage control because of a lack of available drawdown. Drainage control can be accomplished by the use of drainage tiles. For tile drainage it was assumed that tile depth would be restricted to 7.5 feet and that the water table would be maintained at a depth of five feet.

Subarea 2 - Areas with less than 15 feet of saturated aquifer; water table more than 5 feet below land surface. There is a lack of opportunity for the use of wells for drainage in this subarea as is the case in Subarea 1. In addition, the use of drainage tiles is also constrained by the greater depth to water table. In much of the area depth to water table is greater than 7.5 feet and tile depths in excess of 10 feet would be required.

Subarea 3 - Areas with more than 15 feet of saturated aquifer; water table less than 7.5 feet below land surface. In Subarea 3, both drainage wells and drainage tiles can be used to control water table levels. The number of wells required for drainage control decreases with the increase in thickness of the saturated aquifer and the spacings for drainage tile increases with increasing dkepth to the base of the aquifer unit until a critical depth is attained. Beyond the critical depth, ranging from about 40 to 60+ feet, depending on the diameter of the drainage tile, a constant tile spacing of about 1500 feet is anticipated. Within the subarea, control of water table levels to a depth of 10 feet can be readily accomplished, whereas drainage by tiles is assumed on the basis of a five-foot water table depth. Decisions regarding use of tiles or wells within this subarea can be based on depths to water table required and on the relative differences in cost and operating requirements between wells and tiles.

Subarea 4 - Areas with more than 15 feet of saturated aquifer; water table more than 7.5 feet below land surface. The depth to water table generally excludes or severely limits the use of drainage tile for drainage control. Throughout most of this area saturated aquifer thicknesses are sufficient to

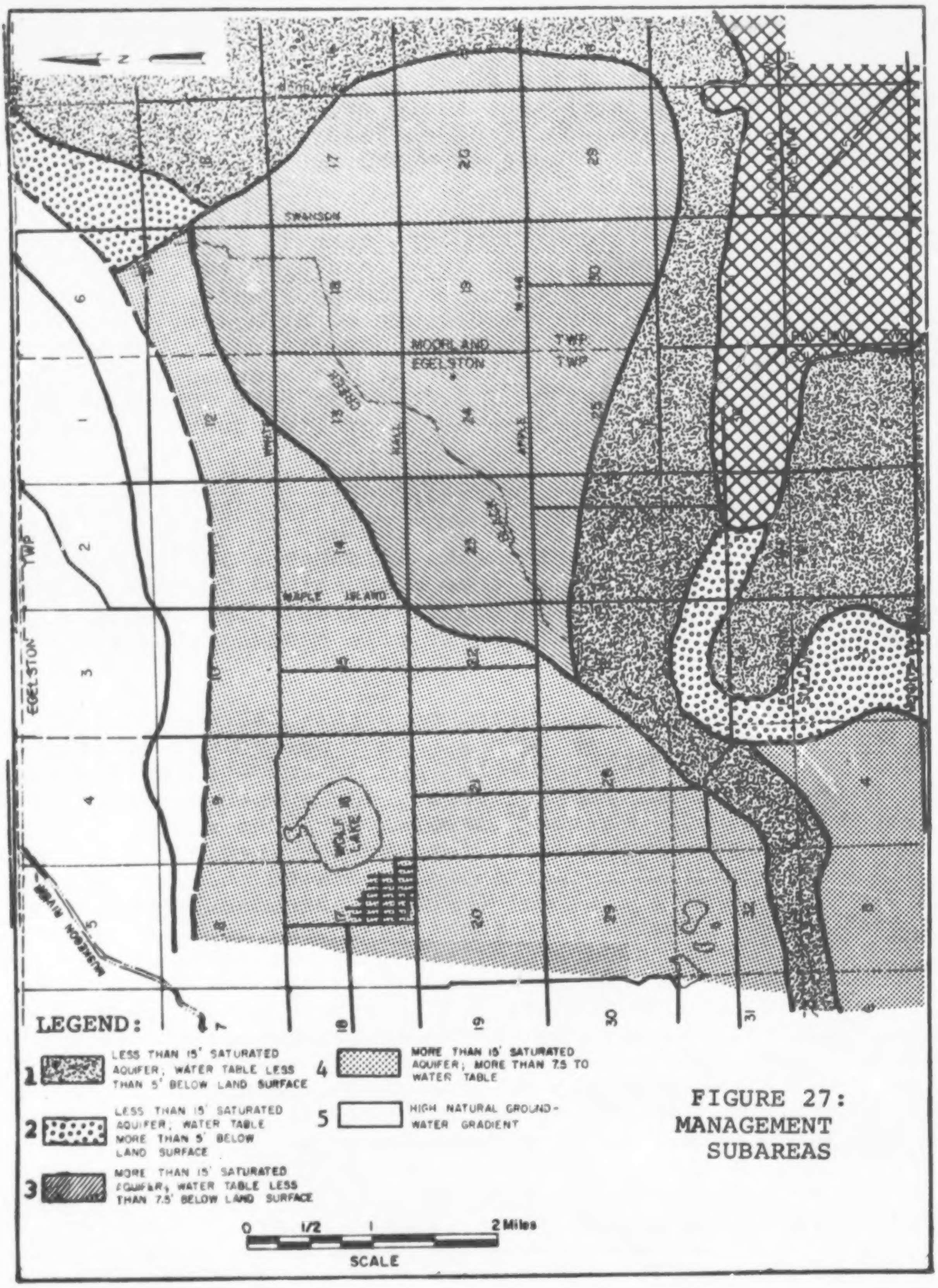

N
SWANSON
MOORLAND TWP
EGELSTON TWP
MAPLE ISLAND
WOLF LAKE
BLACK CREEK
EGELSTON TWP
MUSKEGON RIVER
LEGEND:
1 LESS THAN 15' SATURATED AQUIFER; WATER TABLE LESS THAN 5' BELOW LAND SURFACE
2 LESS THAN 15' SATURATED AQUIFER; WATER TABLE MORE THAN 5' BELOW LAND SURFACE
3 MORE THAN 15' SATURATED AQUIFER; WATER TABLE LESS THAN 7.5' BELOW LAND SURFACE
4 MORE THAN 15' SATURATED AQUIFER; MORE THAN 7.5 TO WATER TABLE
5 HIGH NATURAL GROUND-WATER GRADIENT
0
1/2
1
2 Miles
SCALE
7
18
19
30
31

FIGURE 27: MANAGEMENT SUBAREAS

provide high transmissibilities and wells would generally function as an effective means of control.

Subarea 5 - Areas with a high natural gradient that is adequate to discharge rainfall and wastewater infiltration without well or tile control. A part of the project area adjacent to the valley of Muskegon River has a high natural gradient for groundwater discharging to this low-lying area. With water level management in effect on the adjacent parts of the project area away from the valley wall, the head above discharge level that can be developed up to the required water table control level will be suffienct to discharge the quantity of water produced from the infiltration of rainfall and applied wastewater within the area without special drainage provisions. The boundary of the subarea with these qualifications has not been defined and its position on the area map is therefore presented as indefinite.

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SECTION IX

IRRIGATION AGRICULTURAL STUDIES

Introduction

A part of the irrigation system investigations was the preliminary appraisal of the agricultural aspects of the project. This study was made by the Department of Agricultural Economics of Michigan State University, East Lansing, Michigan and included inputs from various agricultural disciplines.

In addition to a review of the soils within the irrigation site study area, various agricultural management alternatives were considered. Included were the following:

1. Sod production
2. Perennial grasses to be harvested as hay or pasture
3. Continuation of Christmas tree production in selected areas
4. Beef cattle operations

An evaluation of these options resulted in the general conclusion that the preferable alternative for the early stages of the project would be the production of perennial grasses with harvesting as hay or pasture. It was anticipated that the implementation of other agricultural management alternatives, such as cultivated crop production or beef cattle operations, could follow.

Of particular interest in these investigations was the analysis of the economic aspects of the project. The results of this work are included in this report.

Assumptions

Although it was recognized that groundwater level management would result in adequate drainage of the soils within the study area,the soils were classified within the following agricultural management groups:

1. Group a - Naturally well drained

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2. Group b - Somewhat poorly drained

3. Group c - Poorly drained

The total tons of forage dry matter produced are based on a medium level of yields for the establishment period and three levels of yields for the long-run period for the irrigated areas (see Table 27). Only a medium level of yields was assumed for the nonirrigated land. The carrying capacity as measured by number of steers that could be supported on the forage produced was based on a 50 percent and a 75 percent utilization of dry matter produced.

It was assumed that a well established seed bed would be essential in controlling erosion, and in providing the basis for rental of the land to interested parties for harvesting hay or grazing livestock.

The cost of establishing a grass stand on 7,550 acres of irrigated land totals $155,135 or about $15.50 per acre for the 9,950 acres (Table 28). Two thousand acres of cleared land would not need to be seeded. If these costs were amortized over a 10-year period, this would add $1.55 an acre to annual costs (disregarding interest costs).

Costs of harvesting, hauling, and storing the hay crop were based on current custom rates with some modifications for the labor charge included. These per acre figures reflect the cost of owning and operating mowers, rakes, windrowers, balers, and wagons and the extra seasonal labor required to harvest the crop. The costs are based on three cuttings for the irrigated land and two cuttings for the nonirrigated land.

Hay was prices at three levels to provide a range due to differences in quality and distance to market. The following prices were used in arriving at net returns.

Assumed price for hay:

Level of prices	Per ton dry matter	Per ton 90% hay
Low	$14	$12.60
Medium	18	16.20
High	22	19.80

The costs and returns for the steer enterprise were based on recent cost-price relationships and reflect good management.

TABLE 27: LAND ACREAGES AND ESTIMATED DRY MATTER PRODUCTION

Item	Unit	Irrigated Land: Soil Mgt. Group a	Irrigated Land: Soil Mgt. Groups b and c	Irrigated Land: All Irrigated Land	Nonirrigated Land: Soil Mgt. Groups b and c**	All Land in Production
Total Land	Acre	5,550	4,400	9,950	1,790	11,740
Dry Matter Production:						
Establishment period*	Ton	5,550	7,440	12,990	1,970	14,960
Long-run period						
Low yields	Ton	9,710	11,000	20,710	3,220*	23,930
Medium yields	Ton	12,500	14,300	26,800	3,220	30,020
High yields	Ton	16,650	17,600	34,250	3,220*	37,470

*Medium yields.

**No yields assumed for soil mgt. Group a.

TABLE 28: ESTIMATED COSTS IN ESTABLISHING GRASS STAND

Cost Item	Total Units	Cost Per Unit	Total Costs
Soil Tests	100	$3.00	$ 300
Fertilizer to establish cover crop and seed			
Fertilizer material	7,550 acres	7.00	52,850
Cover crop			
Seed (rye, oats, or proso millet)	7,550 acres	1.50	11,325
Planting seed and applying fertilizer	7,550 acres	2.00	15,100
Grass seed establishment			
Grass seed			
Smooth bromegrass	33,300 lbs.	0.35	11,655
Timothy	30,200 lbs.	0.20	6,040
Reed canarygrass	10,000 lbs.	0.85	8,500
Orchardgrass	34,200 lbs.	0.45	15,390
Discing and cultipacking	7,550 acres	2.00	15,100
Planting seed-drill and cultipack	7,550 acres	2.50	18,875
Total all costs			$155,135

The Hay Crop Alternative

The per acre and total costs of harvesting, hauling, and storing the hay crop from the 9,950 acres of irrigated land are shown in Table 29. These represent three yield relationships for the "a" and "b" and "c" soils. Per acre costs, not including establishment of the sod, ranged from $24.52 to $32.40 for the "a" soils to $29.25 to $38.70 for the "b" and "c" soils.

The gross value of the hay crop was calculated for the two soil groups using three levels of yields and three levels of prices. Gross receipts per acre for the "a" soils ranged from a low of $24.50 for the low yield and low price to a high of $66 based on the high yields and a high price. These same gross receipts for the "b" and"c" soils ranged from $35 to $88 per acre. A summary of these relations is shown in Table 30. The low price of $14 could represent material that would be suitable for bedding or feeding to low quality cattle. The lower quality hay would also be acceptable for winter feeding of beef cows.

The net return is the residual return after deducting expenses from the gross value of receipts. This is what a farmer would have left to pay a rental rate, to cover risks, and to pay himself for his contribution to management and labor in harvesting, storing, and either selling or feeding the harvested crop. A look at these net returns for the combined soil groups on irrigated land shows a wide range. With hay priced at $14 per ton, returns are low even at the high level of yields (Table 30). If a charge of $1.50 were made to cover establishment costs, an operator harvesting 400 acres would have a return of $11.50 per acre or $4,600 for his labor, management, and land. Any rental charge would further reduce this return.

With a medium level of yields and a price of $18 or more per ton of hay harvested, more reasonable returns are available to cover management, labor, land rental, and risk ($18.53 - $26.79). Returns on the nonirrigated land are quite low because of the expected yields (1.7 tons dry matter per acre). This is, of course, the reason why much of the cleared land in the area is not utilized except on a marginal basis for crop production. Net returns for the long-run period ranged from $3.05 to $17.44 per acre (Table 31).

The Steer Enterprise

The costs and returns per steer for the grazing period were based on a net gain of 210 pounds, starting with a 600

TABLE 29: ESTIMATED ANNUAL PRODUCER COSTS TO HARVEST AND STORE FORAGE

Soil Management Groups and Cost Items	Level of Yields		
	Low	Medium	High
a soils (5,550 acres)			
Mow and windrow	$ 9.00	$ 9.00	$ 9.00
Rake	4.50	4.50	4.50
Bale	5.25	6.75	9.00
Haul and store	5.77	7.43	9.90
Total cost per acre	24.52	27.68	32.40
b and c soils (4,400 acres)			
Mow and windrow	9.00	9.00	9.00
Rake	4.50	4.50	4.50
Bale	7.50	9.75	12.00
Haul and store	8.25	9.72	13.20
Total cost per acre	29.25	32.97	38.70
Total costs (9,950 acres)			
a soils	136,086	153,624	179,820
b and c soils	128,700	145,068	170,280
Totals	264,786	298,692	350,100

TABLE 30: ESTIMATED ANNUAL GROSS RECEIPTS OF HAY CROP

Soil Management Groups and Prices for Hay	Gross Receipts Levels of Yields Low	Gross Receipts Levels of Yields Medium	Gross Receipts Levels of Yields High	Returns to Land, Risk, Management and Labor Levels of Yields Low	Returns to Land, Risk, Management and Labor Levels of Yields Medium	Returns to Land, Risk, Management and Labor Levels of Yields High
Per acre returns						
a soils						
Hay price per ton						
$14	$ 24.50	$ 31.50	$ 42.00	$ -0.02	$ 3.82	$ 9.60
$18	31.50	40.50	54.00	6.98	12.82	21.60
$22	38.50	49.50	66.00	13.98	21.82	33.60
b and c soils						
Hay price per ton						
$14	35.00	45.50	56.00	5.75	12.53	17.30
$18	45.00	58.70	72.00	15.75	25.73	33.30
$22	55.00	71.50	88.00	25.75	38.53	49.30
All soils groups						
Hay price per ton						
$14	29.14	37.70	48.20	2.53	7.67	13.00
$18	37.49	48.55	61.96	10.86	18.53	26.79
$22	45.80	59.23	75.70	19.19	29.21	40.51
Total returns						
All soils groups						
Hay price per ton						
$14	289,975	375,025	479,500	25,189	76,333	129,400
$18	373,025	483,055	616,500	108,039	184,363	266,400
$22	455,675	589,325	753,200	190,888	290,633	403,100

TABLE 31: ESTIMATED ANNUAL COSTS AND RETURNS OF HAY CROP ON NONIRRIGATED LANDS

	Establishment Period		Long-run Period	
	Per Acre	Total	Per Acre	Totals
Costs				
Mow and windrow	$ 6.00		$ 6.00	
Rake	3.00		3.00	
Bale	4.40		7.20	
Haul and store	3.30		5.96	
Totals	16.70	$ 29,893	22.16	$39,666
Gross Receipts				
Hay price per ton				
$14	15.40	27,566	25.20	45,108
$18	19,80	35,442	32.40	57,996
$22	24.20	43,318	39.60	70,884
Net Returns*				
Hay price per ton				
$14	-1.30	-2,327	3.04	5,442
$18	3.10	5,549	10.24	18,330
$22	7.50	13,425	17.44	31,218

***Returns to land, risk, and operator's management and labor.**

pound steer calf and a cost of $26 per cwt. Returns to land, risk, and to the operator's management and labor were $18.89 (Table 32).

The same residual returns were calculated for the steer enterprise as for the hay enterprise (Table 33). These were based on a 50 percent and 75 percent forage utilization and three levels of forage yields. The estimated returns during the establishment period on irrigated pasture are low for the two levels of forage utilization ($9.49 and $14.24). For the long-run period, returns ranged from $15.11 to $25.00 for 50 percent forage utilization, and $22.68 to $37.51 for 75 percent forage utilization. The estimated returns on non-irrigated pasture during the establishment period are quite low (Table 34). For the long-run period, net returns were $13.06 for 50 percent utilization, and $19.61 for 75 percent utilization. The relationship of steer weight to stocking rate is shown on Figure 28. The stocking rate with 600 pound steer calves is about 77 percent as high as for 400 pound steers. Other selected factors affecting producers' costs and returns are shown in Table 35. Dairy heifers may be another feasible alternative for grazing the forage produced in the waste disposal area.

Potential Full Time Employment and Rental Rates

A problem in maximizing rental returns from the irrigated land is arranging for sufficient operators to either harvest all of the acres for forage or to provide sufficient animals to fully utilize the forage. Assuming one man can harvest approximately 400 acres of forage with an adequate set of equipment, a rough approximation is that 25 farmers would be needed to harvest the irrigated forage as hay. One man can also probably look after 1,000 head of steers, except during times when they need to be treated or moved. With medium yields and a 75 percent forage utilization, 15 cattlemen would be needed for the irrigated acreage. It would require 10 cattlemen with medium yields and a 50 percent forage utilization. Of course, the simplest solution in arranging for a sufficient number of operators would be to lease the entire acreage to one firm.

The current cash rental rate for pasture and hay land in western Michigan is typically $10 per acre. It is unknown whether producers would be willing to pay this price (or a higher one) at this time.

The return estimates previously discussed did not completely charge for the producers' management and labor.

TABLE 32: ESTIMATED ANNUAL STEER COSTS AND RETURNS

Item	Unit	Price or Cost/Unit	Amount	Value
Gross Returns:				
Feeder Steer		$24.50*	$ 8.1	$198.45
Specified Costs:				
Feeder Steer	cwt.	26.00	6	156.00
Hauling (to pasture)**	animal	2.00	1	2.00
Hauling (from pasture)***	cwt.	.25	7.98	2.00
Interest on operating cost	dol.	.075	156.00	11.70
Death loss	% of initial cost	.15	156.00	2.34
Veterinary and medicine	animal	1.00	1	1.00
Salt and minerals	animal	.60	1	.60
Shrinkage loss****	cwt.	24.50	.16	3.92
Total Specified Costs				179.56
Return to land, risk, and the operator's management and labor				18.89

*Based on Kansas City price relationships.

**Hauling and commission charges.

***Assumes a price of 15 cents per hundredweight per 100 miles.

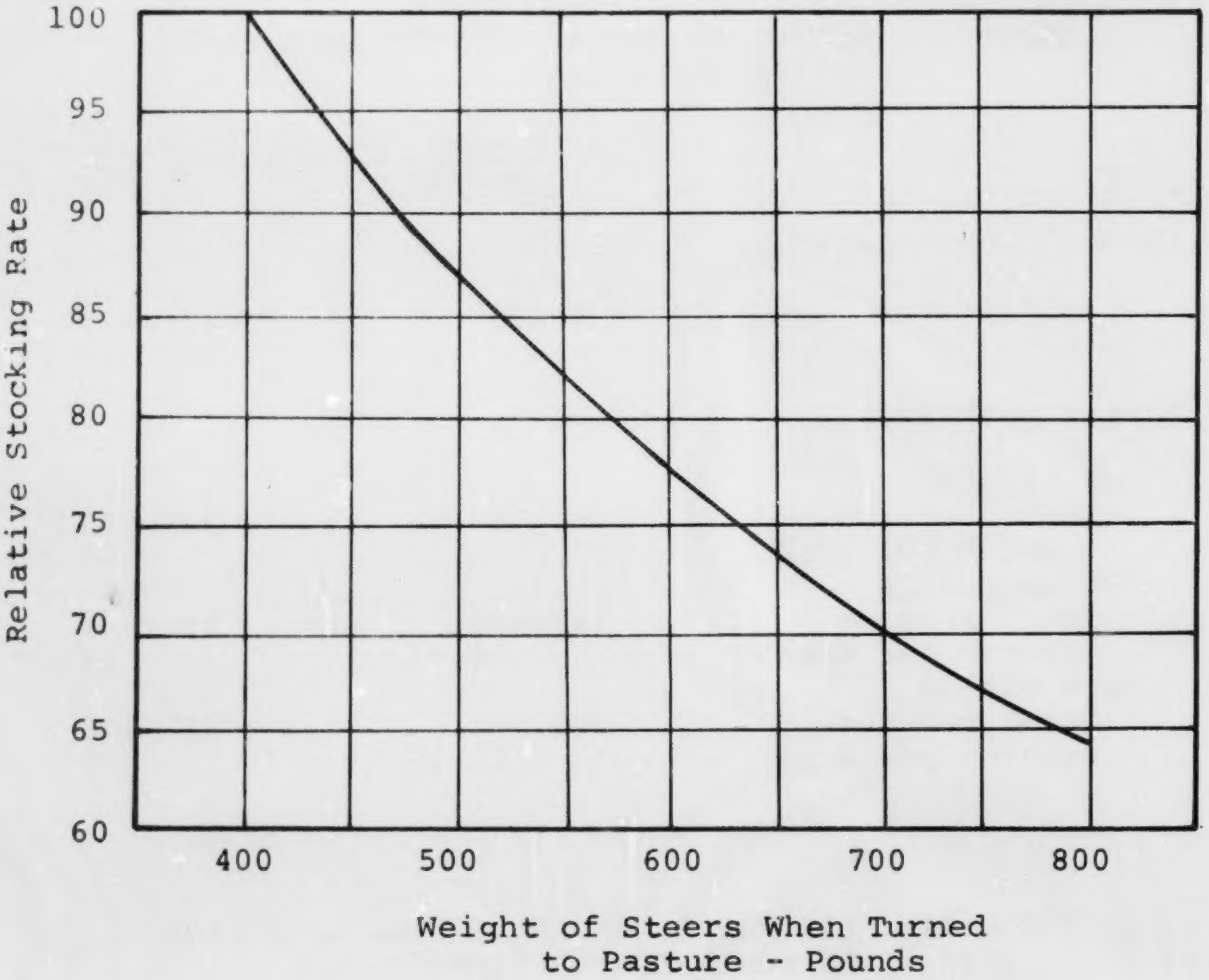
****Assumes a two percent shrinkage on weight gained.

TABLE 33: ESTIMATED ANNUAL RETURNS OF STEERS ON IRRIGATED LAND

Item	Returns with Forage Utilization of 50 Percent	75 Percent
Establishment period:		
Total returns	$ 94,450	$141,675
Returns per acre	9.45	14.24
Long-run period:		
Low yields		
Total returns	150,364	225,660
Returns per acre	15.11	22.68
Medium yields		
Total returns	189,467	292,039
Returns per acre	19.04	29.35
High yields		
Total returns	248,781	373,266
Returns per acre	25.00	37.51

TABLE 34: ESTIMATED ANNUAL RETURNS OF STEERS ON NONIRRIGATED LAND

Item	Returns with Forage Utilization of 50 Percent	75 Percent
Establishment period:		
Total returns	$ 14,319	$ 21,478
Returns per acre	8.00	12.00
Long-run period:		
Total returns	23,386	35,098
Returns per acre	13.06	19.61



Notes: 1. Curve based on pasture having carrying capacity for 100 head of 400 pound steers.

2. Daily gain is 1.5 pounds - 200 pounds total net gain from May 15 to October 15.

Source: Henderson, H. E., and Greathouse, T. R., Department of Animal Husbandry, Michigan State University.

FIGURE 28: PASTURE STOCKING RATE FOR YEARLING STEERS

TABLE 35: POTENTIAL EFFECTS ON COSTS AND RETURNS

Item	Potential Effect
Conditions of animals	The condition of animals when turned to pasture heavily influences the daily summer gain. The higher the daily winter gain, the smaller the daily summer gain. This can be explained in the following equation: Daily summer gain = 2 - (.6 X daily winter gain)*
Sex of animals	Heifers produce up to 15 percent less gain than steers, but have similar stocking rates and costs.*
Type of cattle	Daily steers out gain beef type steers of comparable age and weight.** Cross breds achieve up to 10 percent greater gain than straight breds.***

*Henderson, H. E., Department of Animal Husbandry, Michigan State University.

**Henderson, H. E., "Comparative Feedlot Performance of Dairy and Beef Type Steers," Proceedings of Cornell Nutrition Conference for Feed Manufacturers, 1969.

***Gregory, K. E., et. al., "Heterosis Effects on Growth Rate of Beef Heifers," Journal of Animal Science, Vol. 25, May 1966.

This cost must be deducted in order to more clearly assess potential rental charges. The hay operation essentially requires four months of a producer's time. (Although he may not be fully employed for this entire period, he probably cannot hold another job.) Assuming a 40 hour week and a $2.50 charge per hour for the producer's time, the total annual cost of the producer's labor and management amounts to $1,600, or $4 per acre. For the livestock operation, approximately five months of a producer's time is required. Again, assuming a 40 hour week and a $2.50 charge for labor, the total annual cost amounts to $2,000 for a producer's labor and management. Since one man can probably look after 1,000 head, this cost per head amounts to $2.

Tables 36 and 37 show the estimated returns to land and the producer's risk after the costs of the producer's management and labor have been deducted. These figures are potentially the maximum rental rates per acre that could be paid with these enterprises. The actual rental rates that farmers would be willing to pay would be something less than these estimated values.

TABLE 36: ESTIMATED ANNUAL RETURNS FOR HAY

	Hay Price Per Ton		
Level of Yields Assumed*	$14	$18	$22
Irrigated Land:			
Low yields	$-1.47	$ 6.86	$15.19
Medium yields	3.67	14.53	25.21
High yields	9.00	22.79	36.51
Nonirrigated Land**	- .96	6.24	13.44

*Not computed for establishment period.
**Only medium yields assumed.

TABLE 37: ESTIMATED ANNUAL RETURNS FOR STEERS

Level of Yields Assumed*	Returns with Forage Utilization of 50 Percent	75 Percent
Irrigated pasture:		
Low yields	$13.51	$20.28
Medium yields	17.03	26.24
High yields	22.36	33.54
Nonirrigated pasture**	11.68	17.53

*Not computed for establishment period.
**Only medium yields assumed.

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SECTION X

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SECTION XI

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